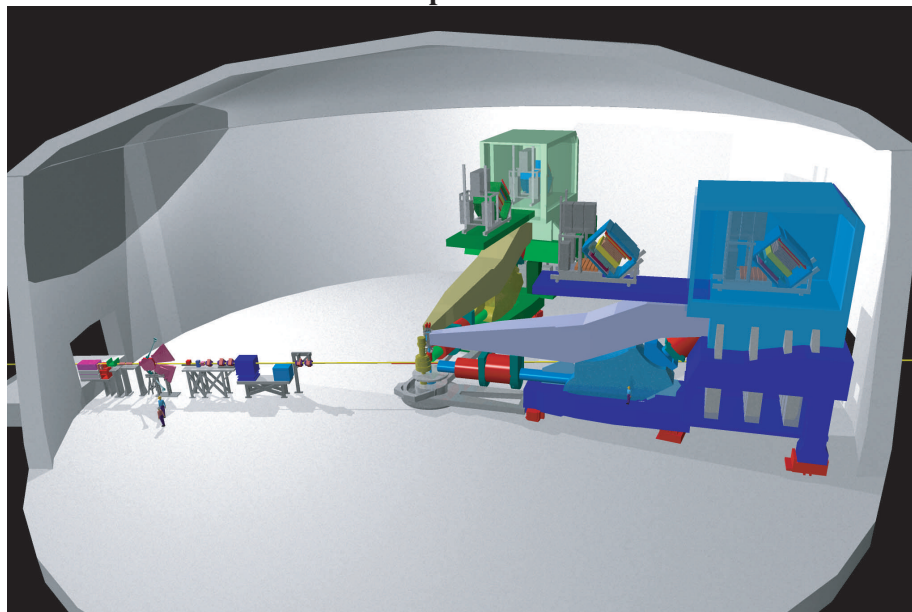


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Hall A Experimental Equipment Operations Manual and Safety Assessment

Info Level 4

Hall A Arms and Beamline Transport



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The Hall A Collaboration

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Chapter 1

Introduction

1.1 General ^{1 2}

This document contains the following information concerning the Hall A “base equipment”:

- safety assessment
- technical overview
- operating procedures
- performance information

The operating procedures are intended to provide shift personnel with the information they need to understand, at least at a rudimentary level, the function of the various subsystems in the end-station. It should also aid in determining if the equipment is performing properly and provide instructions for what to do in the case of malfunctions. This document is not intended to be a comprehensive reference but is rather a guide for the use of on shift personnel. When appropriate, other references are indicated for the user who requires more information.

It is assumed that the reader of this document has been through all the required Jefferson Lab safety training. Hence, the material covered in those courses is for the most part not repeated here. End-station specific safety items are covered in “The Experiment Safety Assessment Document for the Hall A Base Equipment” which is required reading for all shift personnel. This document also contains some safety information when deemed appropriate.

1.2 The Personnel Safety System

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Users and staff working on the accelerator site are protected from the dangers associated with the prompt ionizing radiation that the accelerator beam produces by the Personnel Safety System or PSS. The PSS keeps ionizing radiation out of areas where people are working, and keeps people out of areas where ionizing radiation is present.

There are a total of five states for the Hall A Personnel Safety System: Restricted Access, Sweep, Controlled Access, RF Power Permit, and Beam Permit.

1.2.1 Restricted Access

Restricted Access is the PSS system state when delivery of beam and/or RF power is not permitted, and entry to and exit from the hall is not controlled by the Personnel Safety System. This is the normal state of the hall when the accelerator is off and no experiments are running. Access is “restricted” only in the sense that the hall is not open to the general public.

1.2.2 Sweep

Sweep is the state of the PSS when delivery of beam and/or RF power is not permitted and access is limited to the Jefferson Lab personnel conducting the sweep operation. The hall’s entrance gates are closed from the inside to ensure that no one can enter behind the person conducting the sweep. During the sweep, an Assigned Radiation Monitor or ARM systematically searches the hall to verify the absence of people and to arm the run/safe boxes. The ARM posts a guard at the entrance to the hall as another method of ensuring that no one enters after him.

When the Assigned Radiation Monitor is ready to perform a sweep, the Machine Control Center or MCC must first place the hall in the Sweep state. The Personnel Safety System will read “Sweep In Progress.” Once the hall is placed in the sweep state, the sweep monitors enter the first gate to the hall, making sure it locks behind them. The ARM then notifies the MCC that he is ready to begin the sweep. The MCC communicates with the sweep monitors via intercom and video camera. Using the video camera, the MCC makes sure both sweep monitors are wearing the proper dosimetry. At this point the ARM also indicates that he is in possession of the key needed to arm the Run/Safe boxes placed throughout the hall. Having confirmed that the dosimetry is adequate, the MCC will unlock the second entrance gate allowing the sweep monitors to enter the hall. Once the sweep monitors pass through the second gate, they close the gate and ensure it is locked. The sweep monitors then proceed to the hall entrance where one sweep monitor is left to guard the entrance and the other begins the sweep. During the actual sweep, the ARM walks through every area and secluded workspace in the hall to ensure that no one could be left inside when the Personnel Safety System moves from the sweep state to controlled access, power permit, and finally beam permit state. Once he checks an area, he arms the run/safe box in that area. After all areas of the hall have been checked and the run/safe boxes armed, the sweep monitors will return to the entrance where the sweep began. Before arming the last run/safe box, the ARM will contact the MCC. Upon contact, the MCC will check to see if the sweep has “dropped”; if all is well he will notify the ARM that it is okay to arm the box. Once the box is armed, the sweep

monitors have 30 seconds to exit both gates or the sweep will drop, and the entire sweep process will have to be repeated. After exiting, the ARM must contact the MCC to let them know the Hall can now be moved to the controlled access state.

1.2.3 Controlled Access

Controlled Access is the state of the PSS when delivery of beam and/or RF power is not permitted but the hall is considered a controlled area. In this state, people are “counted” both entering and leaving the hall to ensure that no one is left inside when the Personnel Safety System advances to the RF Permit or Beam Permit states. Hall entry during the controlled access state is permitted only to people authorized or qualified by Jefferson Lab . Entry to and exit from the hall is controlled from the MCC. The Hall cannot be placed in the “controlled access” state without having first been swept.

1.2.4 RF Power Permit

When the PSS is in RF Power Permit the hall is considered an “exclusion area”. Delivery of RF power is permitted, but beam delivery is not. Reaching this state requires that the hall has passed through the controlled access state and that no one is left inside the hall. This is usually a temporary state bridging the transition from the Controlled Access to the Beam Permit state. Once the Personnel Safety System reads “Power Permit”, a steady klaxon sounds in the hall. If you are in the hall when this klaxon sounds, press the emergency safe button on the nearest run/safe box and immediately exit the hall. The hall entrance gates are locked at this time, but there is an emergency exit button at each gate which will allow you to exit. A four-minute delay is built in between the transition from RF Power Permit to Beam Permit.

1.2.5 Beam Permit

When delivery of beam and RF power is permitted to the exclusion area the PSS state is Beam Permit. Reaching this state requires having passed through the RF Power Permit state.

1.2.6 Run Safe Boxes

The Personnel Safety System includes Run/Safe boxes which are located throughout Hall A, and approximately every 100 feet in the linac. A run/safe box has three positions: Safe, Operational, and Unsafe. When the hall is in Restricted Access, the run/safe box will be in the Safe position. While in this position, the PSS prevents delivery of beam to the hall. Before beam can be delivered, the hall must be swept to ensure that no one is left inside. During the Sweep, each run/safe box is moved to the Operational position in preparation for Beam Permit. After the sweep has been completed and the hall is placed in the RF Power Permit state, the run/safe box will show Unsafe. Each box has an emergency stop button. If you see the box in the Unsafe position, you are in danger of receiving high levels of ionizing radiation. Immediately press the emergency stop button, exit the hall, and call the Machine Control Center Crew Chief at extension 7050.

1.3 Hall A Access

Access to Hall A is governed by the “Jefferson Lab Beam Containment Policy and Implementation” document. This document can be found in the Jefferson Lab ES&H Manual (Section 6310, Appendix T2). Work in designated radiation areas will be governed by the Jefferson Lab RadCon Manual. Access procedures during Research Operations depend on the number of individuals who will be entering the hall and the length of time they are expected to be there. A controlled access is used when a few individuals require entry for a short period of time. If the hall must be open for an extended period and many people will enter, then you should use the restricted access procedure instead of the controlled access procedure. Normally, when requesting a controlled access, the hall will be in either the Beam Permit or RF Permit State - for example, if the beam has been on or it could be shortly. If the hall is not already in the Controlled Access state when you wish to access it, you must request a change to that state from the Machine Control Center at extension 7050 and indicate that you intend to make a Controlled Access. The MCC will then send an Assigned Radiation Monitor to survey the hall. Before anyone enters the hall, the ARM will carry out a radiation survey and post radiation areas. Subsequent entry by individuals during the same Controlled Access period does not require an ARM survey.

1.3.1 Controlled Access Procedure

To make a controlled access when the hall is in the controlled access state, first contact the MCC. The MCC will unlock the first gate at the entrance to the hall. Once inside, the MCC will release the master key. Remove the master key and insert it into the right-most slot of the row of keys below it. Once the master key is in place, each person wishing to gain access must remove a key from this row. The MCC will then verify each person’s name, which key he has, and check that each person is wearing the proper dosimetry. This key-release procedure allows the MCC to keep a “count” of who has entered the hall. After the procedure is complete, the MCC will unlock the second gate at the entrance to the hall. Please note: only one of the entrance gates can be open at a time while in the controlled access state.

When your work is completed and you are ready to exit, return to the entrance gates and press the intercom call switch to notify the MCC. Once you have entered and closed the first gate, each person must replace his key in the appropriate slot, otherwise the Personnel Safety System will not allow the master key to be released. When the master key is released, place it in its slot, and the MCC will unlock the final gate. When you have exited the final gate, make sure it has closed and locked behind you. If circumstances dictate, request that the MCC return the hall to the beam permit state and that beam be restored. It is important to note that if you need to work in the HRS shield house during the controlled access, you must go to the control room in the MCC before the access and get a special key which allows you to arm the run/safe box located in the shield house. The run/safe box inside the shield house will drop from the operational position to the safe position as soon as the door to the shield house opens. Unless this

box is rearmed with the special key, the beam cannot run.

1.3.2 Restricted Access Procedure

Restricted Access is used when the hall will be open for an extended period of time or a large group will enter to work. To drop the hall to the Restricted Access state, first notify the MCC that you wish to open the hall in the Restricted Access state. The MCC will drop the hall status to Controlled Access and send an ARM to survey the hall. Before anyone can enter the hall, the ARM will carry out a radiation survey and post radiation areas. The hall is placed in Controlled Access during the survey to ensure that no one enters before it has been completed. Upon completion of the survey and posting of radiation areas, the ARM will leave the hall and notify the MCC that they can drop the hall state to Restricted Access. With the hall in the Restricted Access state, anyone with the appropriate training may enter and work. The key- release procedure is not required.

To return the hall to Beam Permit from the Restricted Access state, a full inspection must be carried out. This is begun by setting all equipment to its operating state (following the Hall A checklist) and then clearing all workers out of the hall. Next, a request is made to the MCC to arrange a sweep of the hall and to restore the Beam Permit state. The MCC will send over an ARM and set the hall status to Sweep. The ARM will then sweep the hall, verifying that everyone is out. Following a successful sweep, the MCC can move the hall through the Controlled Access and RF Permit states to the Beam Permit state. While working in the hall you must observe all posted radiation areas. Remember, work inside a radiation area requires that you obtain an approved radiation permit. You must also observe the “two-man” rule, and pay attention to the alarms.

1.3.3 Access Requirements

Normally only registered experimenters, authorized contractors or sub-contractors and Jefferson Lab employees may enter experimental areas. In addition, lab policy states that no one under eighteen years of age is allowed access to the experimental halls.

Lab visitors may work in the halls provided they have completed the full complement of training courses (EH&S Orientation, ODH, Rad Worker Training and any hall specific training (the Hall A safety walk through). They must also read/sign any appropriate documentation (typically the COO and ESAD for the current experiment and the Hall RWP).

In addition to the above, undergraduate students must undergo a three month trial period. During this period they may work in the hall provided that:

- Their work in the hall is directly supervised by a hall authorized “buddy” (who CANNOT be an undergraduate)
- Either a JLab staff member or a fully trained user has supervisory responsibility for and is fully cognizant of all their work
- The person with supervisory responsibility has approved the “buddy”.

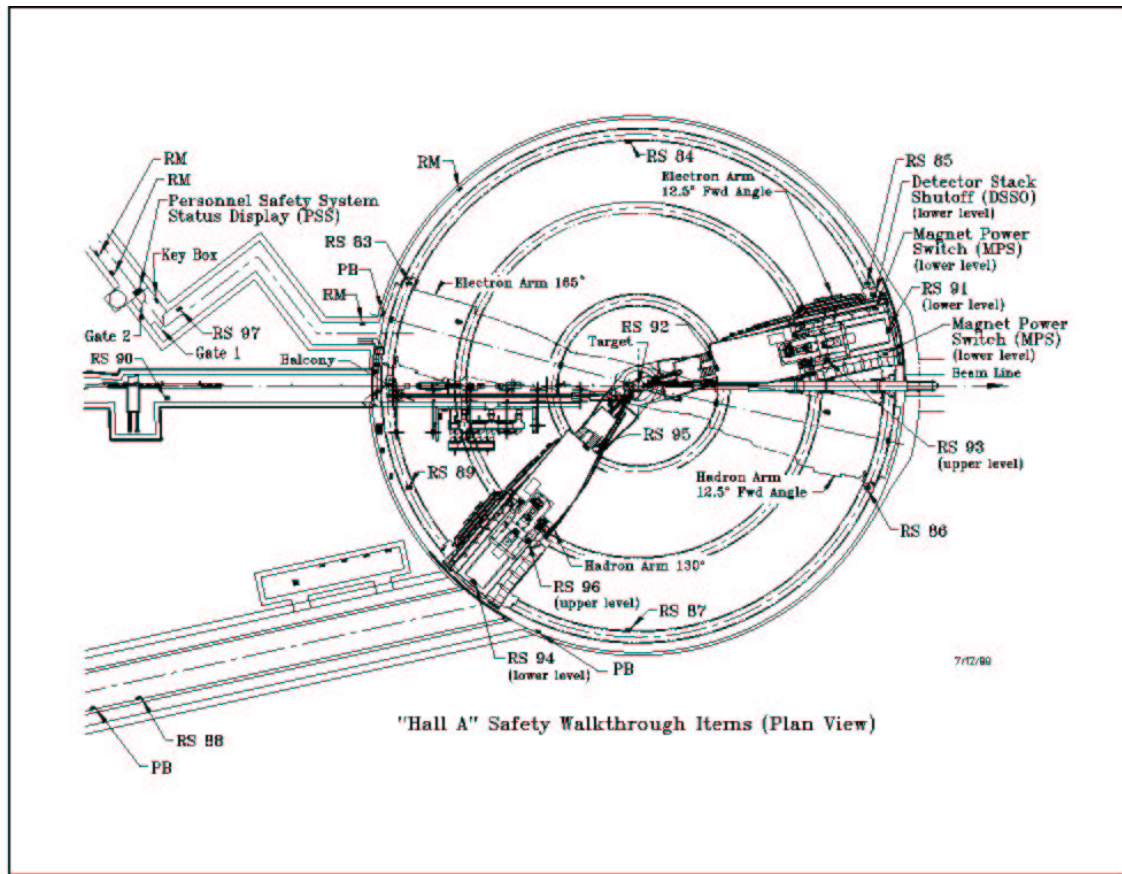


Figure 1.1: Schematic of the Hall A showing the location of various safety system components. The abbreviations are: Radiation Monitor, RM, Run Safe Box, RS, Fire Alarm Pull Box, PB.

After completion of the trial period undergraduates maybe approved for work in the halls under the standard guidelines.

Physics Division EH&S personnel should be contacted to obtain the current policy for conducting tours in the experimental areas.

1.3.4 The Hall A Safety Walk-through

In order to improve user awareness of the systems in the hall, users are required to complete a self-guided safety walk-through the experimental area. Information about the walk-through can be found on the web³. John Lerosé is the JLab staff member responsible for the administration of the Hall A safety walk-through.

Figure 1.1 shows the location of many of the safety related items in Hall A while figure 1.2 shows the location of all the circuit breaker boxes in the hall.

³<http://hallaweb.jlab.org/news/minutes/walkschd.html>

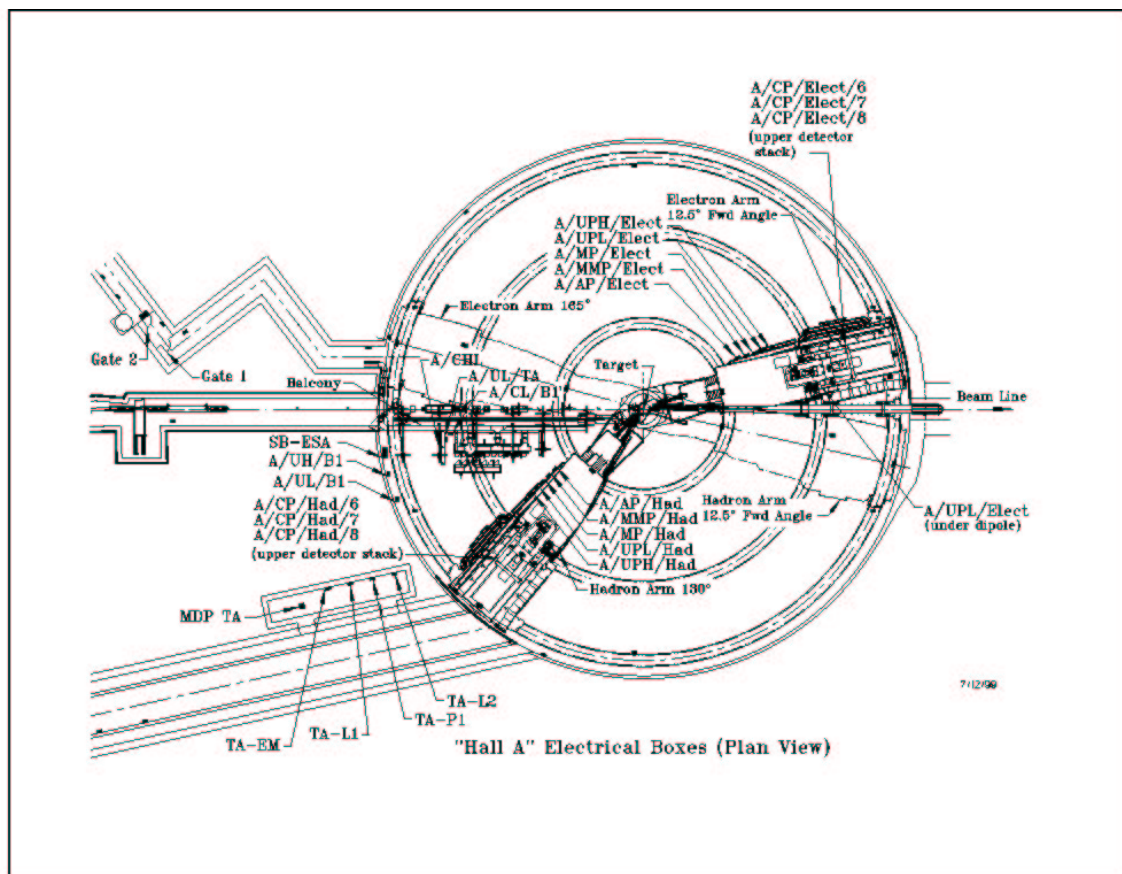


Figure 1.2: Schematic of the Hall A showing the location of the circuit breaker panels.

Chapter 2

Beamline

2.1 General Description ^{1 2}

2.1.1 Introduction

The control and measurement equipment along the Hall A beamline consists of various elements necessary to transport beam with the required specifications onto the reaction target and the dump and to simultaneously measure the properties of the beam relevant to the successful implementation of the physics program in Hall A. The resolution and accuracy requirements in Hall A are such that special attention is paid to the following:

1. Determination of the incident beam energy
2. Control of the beam position, direction, emittance and stability
3. Determination of the beam current, total charge and polarization.

Table 2.1 gives a listing of all the various elements along the Hall A beamline from the switch yard to the dump. Figures 2.1, 2.2, 2.3 show a schematic of the Hall A line starting at the shield wall.

The basic Hall A beamline consists of the following:

1. The Beam Entrance Channel

The beam entrance channel consists of stainless steel tubing connected with conflat type flanges. The usual opening is 2.5 inches for better vacuum conductance except through magnetic and beam diagnostic elements where it is usually 1 inch. Sections are isolated by vacuum valves and these are listed in Table 2.1. Each section has a roughing port and is pumped with an ion pump. The pressure is about 10^{-6} Torr. There are several sections along the beamline where users interface their equipment. Their individual systems are tested leak tight (to $\leq 10^{-9}$ Atm cm³/sec).

¹ CVS revision Id: beam.tex,v 1.3 2003/06/06 15:19:02 gen Exp

²Authors: A.Saha <mailto:saha@jlab.org>

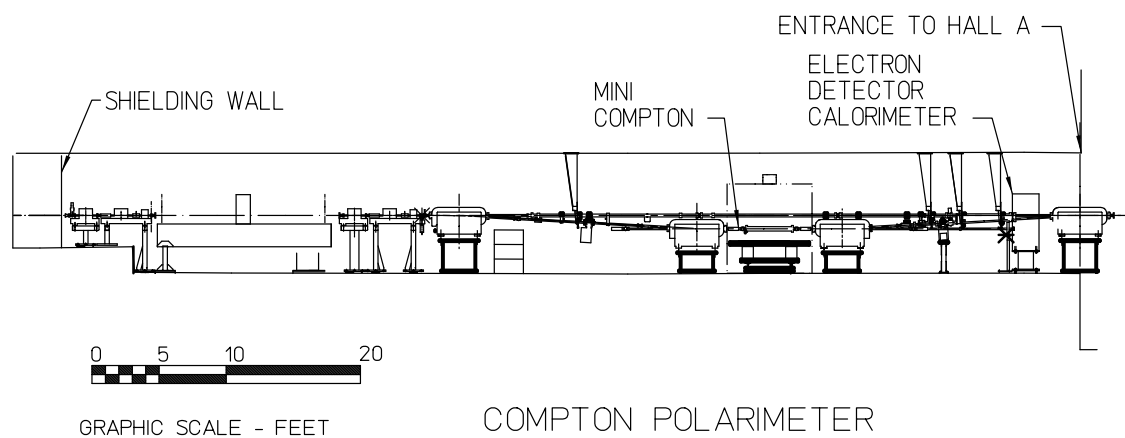


Figure 2.1: Schematic of the Hall A beamline starting at the shield wall to end of alcove.

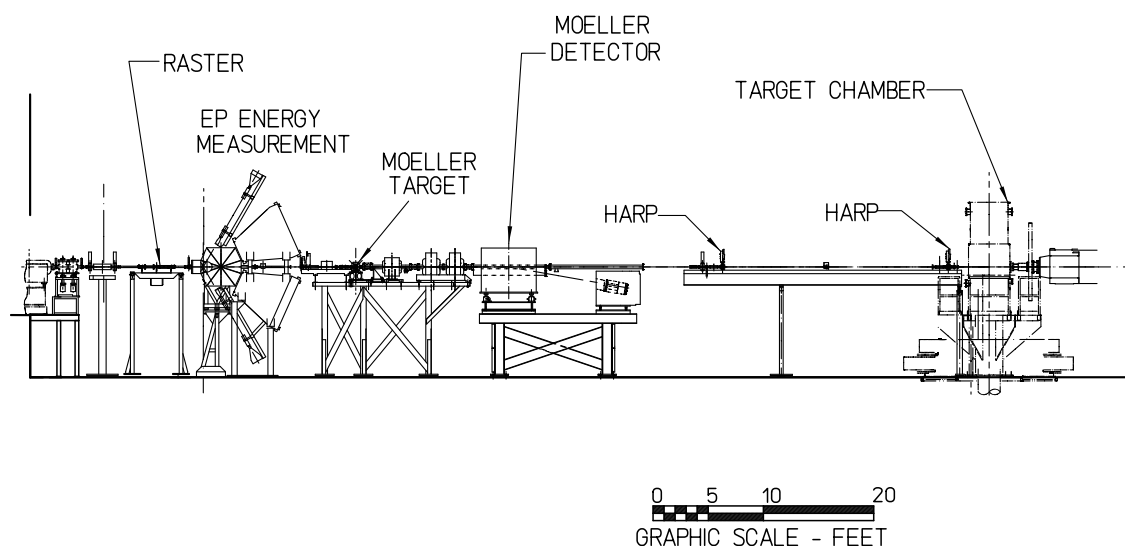


Figure 2.2: Schematic of the Hall A beamline from the end of the alcove to the target chamber.

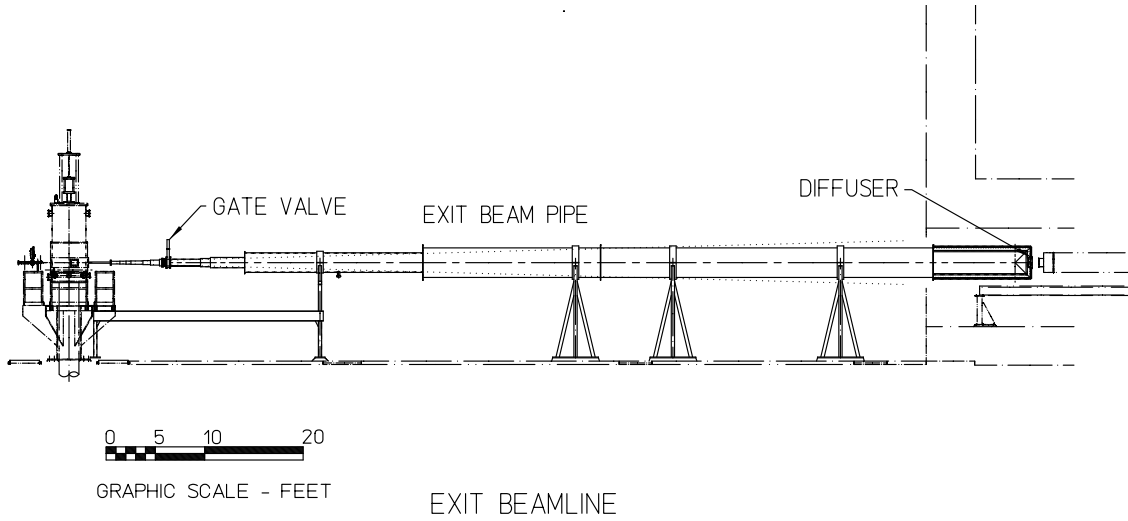


Figure 2.3: Schematic of the Hall A beamline from the target chamber to the dump diffuser.

2. The Beam Optics Channel

These consist of dipoles, quadrupoles, sextupoles, and beam correctors with their standard girders and stands. Starting from the beam switchyard, there are eight dipoles in the arc section which (along with five other smaller beam deflectors) bend the beam 37.5 degrees into the hall. Each dipole has a quadrupole and a pair of steering magnets (correctors) associated with it. After the shield wall at the entrance to the tunnel into the hall the beam is essentially undeflected onto the target and into the dump.

The beamline optics elements are designed to deliver various optical tunes of the beam on to the physics target as well as simultaneously deliver various optical tunes at other locations along the beamline. These requirements are listed in Table 2.2. For the basic beamline we are able to deliver beam onto the hall A target in the achromatic mode.

3. Beam Diagnostic Elements

These consist of beam position monitors (BPMs), beam current monitors, wire scanners (superharps) and beam loss monitors. The wire scanners are fabricated by Saclay (French collaboration) and four have been installed along the beamline, two before the arc section and two after the arc section. They are essential for the beam energy determination by the arc method. Another two wire scanners are installed on the bench just before the target to determine the beam position and direction of the beam at the target point with high precision and also measure the emittance of the incident beam. They are also used to absolutely calibrate the two associated beam position monitors located in front of the target.

4. Beam Exit Channel

After the target vacuum chamber, which was built by the University of Virginia, there is an exit beam pipe which transfers the scattered beam onto the dump tunnel under vacuum. This exit beam pipe is made of a thin walled aluminum spiral corrugated pipe of welded construction. The largest diameter is 36 inches with a 0.164 inches wall thickness and the smallest diameter is 6 inches with a 0.042 inches wall thickness. The whole assembly is rather light (approximately 800 kg) and is supported by H shaped adjustable stands. To prevent possible linear collapse of the larger diameter sections under vacuum load, four aluminum channels of total cross-sectional area of 3" are welded to its side. A vacuum of 10^{-5} Torr is maintained with a turbomolecular pump. The exit face of this pipe has a 12" port and is connected to the diffuser with a Beryllium window.

2.1.2 Authorized Personnel

All magnets (dipoles, quadrupoles, sextupoles, beam correctors) and beam diagnostic devices (BPMs, scanners, Beam Loss Monitor, viewers) necessary for the transport of the beam are controlled by Machine Control Center (MCC) through EPICS, except for special elements which are addressed in the subsequent sections. The detailed safety operational procedures for the Hall A beamline should be essentially the same as the one for the CEBAF machine and beamline. The Hall A staff liaison with the MCC are:

Primary Contact A. Saha -x7605

Secondary Contact J.P. Chen -x7413

The Liaison between Accelerator Division and Physics Division is:

Liaison H. Areti -x7187

2.1.3 Additional Safety Information

Additional safety information is available in the following documents:

EH&S Manual

PSS Description Document (contact K. Mahoney for a copy)

Accelerator Operations Directive (contact T. Oren for a copy)

OSP - CEBAF Beam Operations (updated annually)

2.1.4 Machine/Beamline protection system

The MPS system is composed of the fast shutdown system (FSD), beam loss monitor (BLM), and gun control system.

The FSD system is a network of permissive signals which terminate at the electron gun and chopper 1. The permissive to the gun and chopper 1 may be inhibited by any device connected to an FSD mode. Devices connected to the FSD system include vacuum valves, RF systems, Beam loss systems, beam current monitors, beam dumps, and particular to Hall A, the target motion mechanism and the raster (value and derivative).

The gun control system includes software program which monitors beam operating conditions and the state of the FSD and BLM systems. the program will warn the operators if a potential for beam damage exists. Potential for damage exists when running high average current beam, when FSD nodes are masked and when the beam power approaches the operating envelope limits for a specific beam dump.

2.1.5 Personnel Safety System

Personnel safety system (PSS) console equipment is located in the main control room. It includes:

- Access control
- Safety interlock
- ODH monitoring
- Radiation monitoring
- Public address system.

Girder #	Diagnostic Elements	Optics Elements	Valves & Pumps	Element #	Distance (m) from target
Beam Switch Yard					
	TV Viewer			ITV2C00	148.12862
1CB2		Dipole (2.3m + 0.13m shim)		MLA1C02	146.60000
1CB3		BD		MBD1C00V	144.18700
			Valve	VBV1C00A	~142.78686
	Current			SBC1C00	~136.99564
	Beam Stopper			SSS1C00	~136.53844
	Beam Stopper			SSS1C00A	~136.08124
1C01	BPM			IPM1C01	134.32465
		BC		MQA1C01	133.95000
			Ion Pump	VIP1C01	133.04195

1C02	BPM			IPM1C02	132.02465
		BC		MQA1C02	131.65000
				MBC1C02V	131.30685
1C03	BPM			IPM1C03	129.02465
		BC		MQA1C03	129.35000
			Ion Pump	VIP1C03	
			Rough Pump	VRV1C03	128.44195
			Convectron	VTC1C03	
1CB4		Dipole (1m)		MBN1C04	116.70000
1C04	BPM			IPM1C04	115.42465
		Quad		MQA1C04	115.05000
		BC		MBC1C04H	114.70685
			Ion Pump	VIP1C04	114.14195
1C05	BPM			IPM1C05	112.12465
		Quad		MQA1C05	111.75000
		BC		MBC1C05V	111.40685
			Valve	VBV1C05A	
			Ion Pump	VIP1C05	
			Rough Pump	VRV1C05	110.84195
			Convectron	VTC1C05	
1C06			Valve	VBV1C06	
	BPM			IPM1C06	104.82465
		Quad		MQA1C06	104.45000
		BC		MBC1C06H	104.10685
			Ion Pump	VIP1C06	103.54195
1C07	BPM			IPM1C07	99.52465
		BC		MBC1C07V	98.61076
			Ion Pump	VIP1C07	98.24195
<hr/>					
Arc Section ↓					
1C08	BPM			IPM1C08	93.42465
		Quad		MQA1C08	93.05000
		BC		MBC1C08H	92.70685
		Sext		MSA1C08	92.40500
	TV View			ITV1C08	92.21180
			Ion Pump	VIP1C08	
1CB5		Dipole (3m)		MBA1C05	90.30000
1C09		Quad		MQA1C09	87.85000
		BC		MBC1C09H	87.50685
		Sext		MSA1C09	87.20500
1CB6		Dipole (3m)		MBA1C06	85.10000
1C10	BPM			IPM1C10	83.02465
		Quad		MQA1C10	82.65000
		BC		MBC1C10H	82.30685

		Sext		MSA1C10	82.00500
			Ion Pump	VIP1C10	81.81180
1CB7		Dipole (3m)		MBA1C07	79.90000
1C11		Quad		MQA1C11	77.45000
		BC		MBC1C11V	77.10685
		Sext		MSA1C11	76.80500
			Covectron	VTC1C11	76.61180
1CB8		Dipole (3m)		MBA1C08	74.70000
1C12	BPM			IPM1C12	72.62465
		Quad		MQA1C12	72.25000
		BC		MBC1C12H	71.90685
		Sext		MSA1C12	71.60500
			Ion Pump	VIP1C12	71.41180
1CB9		Dipole (3m)		MBA1C09	69.50000
1C13		Quad		MQA1C13	67.05000
		BC		MBC1C13V	66.70685
		Sext		MSA1C13	66.40500
1CB10		Dipole (3m)		MBA1C10	64.30000
1C14	BPM			IPM1C14	62.22465
		Quad		MQA1C14	61.85000
		BC		MBC1C14H	61.50685
		Sext		MSA1C14	61.20500
			Ion Pump	VIP1C14	61.01180
1CB11		Dipole (3m)		MBA1C11	59.10000
1C15			Valve	VBV1C15	
			Rough Pump	VRV1C15	
		Quad		MQA1C15	56.65000
		BC		MBC1C15V	56.30685
		Sext		MSA1C15	56.00500
1CB12		Dipole (3m)		MBA1C12	53.90000
1C16			Ion Pump	VIP1C16	
			Convectron	VTC1C16	
	BPM			IPM1C16	51.82465
		Quad		MQA1C16	51.45000
		BC		MBC1C16H	51.10685
			Valve	VBV1C16	
Shield Wall → Hall A					
SHIELD WALL(entrance surface)					50.70700
SHIELD WALL (exit surface)					49.651
1C17	TV Viewer			ITV1C17	49.411
		Quad		MQA1C17	49.100
1C18	BPM			IPM1C18	48.650
		Quad		MQA1C18	48.300

		BC	MBC1C18H	47.957
		BC	MBC1C18V	47.761
French	Scanner		IHA1C18A	47.381
Bench	Scanner		IHA1C18B	43.673
1C19		Quad	MQA1C19	43.000
1C20	BPM		IPM1C120	42.550
		Quad	MQA1C20	42.200
		BC	MBC1C20H	41.857
		BC	MBC1C20V	41.661
		Ion Pump	VIP1C20	41.450
COMPTON Polarimeter Region				41.000
				25.500
		Ion Pump	VIP1C20A	34.500
		Ion Pump	VIP1C20B	29.500
Current				
			IBC1H00	
			IUN1H00	24.500
			IBC1H00A	
Fast Raster			MRA1H00H	23.000
			MRA1H00H	
		Valve	VBV1H00	22.053
eP Energy Target			VTP1H00A	21.650
		Ion Pump	VIP1H00A	20.000
1H01		Valve	VBV1H01	19.020
	TV View		ITV1H01	18.938
	BPM		IPM1H01	18.650
		Quad	MQA1H01	18.300
		BC	MBC1H01H	17.957
		BC	MBC1H01V	17.761
Moller target				17.5000
1H02		Quad	MQM1H02	16.500
			VRV1H02A	
			VTC1H02A	
1H03		Quad	MQO1H03	15.415
1H03		Quad	MQO1H03A	14.758
Moller		Dipole	MMA1H01	13.272
		Ion Pump	VIP1H03A	11.955
Bench		BD	MBD1H03H	8.132
	BLM		IBC1H03A	7.906
		Valve	VBV1H03A	7.786
	BPM		IPM1H03A	7.524
	Scanner		IHA1H03A	7.353
		Ion Pump	VIP1H03B	4.486
			VTC1H03A	

BPM	IPM1H03B	1.286
Scanner	IHA1H03B	1.122
Valve	VBV1H03B	0.953
Radiator	ERR1H	0.726
TARGET TV Viewer	ITV1H03A	0.000
DUMP Face		-50.000

Table 2.1: Hall A beamline elements from switchyard to Hall A beam dump (revised - 2/2/98)

All distances are from the center of each element to the target (in meters).

Mode	Spot Size $4*\sigma_{x,y}$	Dispersion η	Position Stability	Size Stability
Achromat	$140\mu\text{m}$	0	$50\mu\text{m}$	$50\mu\text{m}$
Dispersive	$\propto \eta\delta$	4m to 12m	$50\mu\text{m}$	$50\mu\text{m}$
Defocussed	0 to 3mm	0	$\pm 10\%$	$\pm 10\%$

Table 2.2: Line A Optics and Beam Requirements at Target

Mode	Spot Size $4*\sigma_{x,y}$	Dispersion η	Position Stability	Size Stability
Energy-eP(d)	$>100\mu\text{m}$	0	$50\mu\text{m}$	$50\mu\text{m}$
Moller Pol. (d)	$>250\mu\text{m}$	0	$50\mu\text{m}$	$50\mu\text{m}$
Compton Pol.	$>80\mu\text{m}$	0	$50\mu\text{m}$	$50\mu\text{m}$
*Energy-arc(d)		15m	$50\mu\text{m}$	$50\mu\text{m}$

Table 2.3: Line A Optics and Beam Requirements at Other Locations.

Notes:

* Build dispersion in arc section with all magnetic elements except dipoles turned off.

(d) Destructive measurements.

Hall A BPM Readout

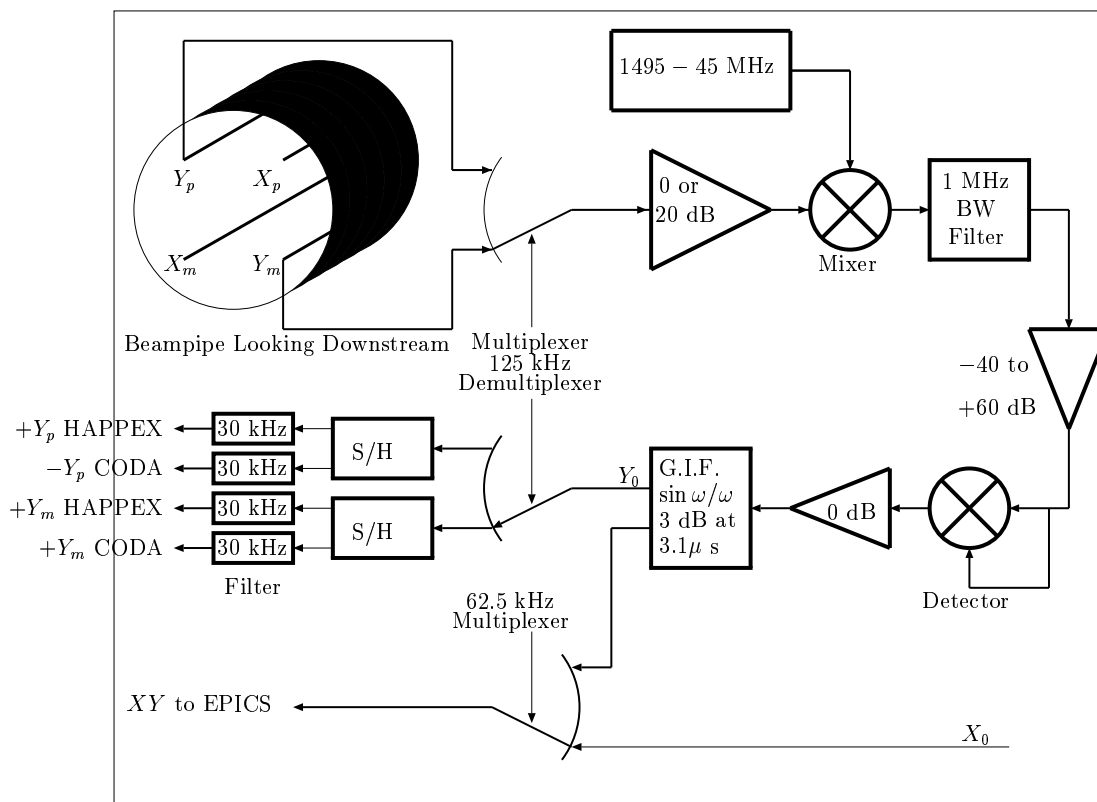


Figure 2.4: Schematic of the BPM readout electronics

2.2 Beam Position Monitors^{3 4}

To determine the position and the direction of the beam on the experimental target point, two Beam Position Monitors (BPMs) are located at distances 7.524 m (IPM1H03A) and 1.286 m (IPM1H03B) upstream of the target position. The BPMs consist of a 4-wire antenna array of open ended thin wire striplines tuned to the fundamental RF frequency of 1.497 GHz of the beam [1]. The standard difference-over-sum technique is then used [2] to determine the relative position of the beam to within 100 microns for currents above 1 μ A. The absolute position of the BPMs can be calibrated with respect to the scanners (superharps) which are located adjacent to each of the BPMs (IHA1H03A at 7.353 m and IHA1H03B at 1.122 m upstream of the target). The schematic of the readout electronics is shown in Figure 2.4. The position information from the BPMs can be recorded in three different ways:

³ CVS revision Id: bpms.tex,v 1.3 2003/06/06 15:19:02 gen Exp

⁴Authors: A.Saha <mailto:saha@jlab.org>

1. The averaged position over 0.3 seconds is logged into the EPICS database (1 Hz updating frequency) and injected into the datastream every 3-4 seconds, unsynchronized but with an orientative timestamp. From these values we can consider that we know the average position of the beam calculated in the EPICS coordinate system which is left handed.

2. Approximately once a shift (or more often if requested by the experimenters) a B-scope procedure [3] can be performed using the same EPICS electronics which then gives the peak-to-peak variation of the beam.

3. Event-by-event information from the BPMs are recorded in the CODA datastream from each of the 8 BPM antennas (2x4) from which the position of the beam can be reconstructed. However, these raw values belong to a parallel electronics chain whose constants have to be retrieved by calibrations to the EPICS or scanner data.

2.3 Beam Current Measurement ^{5 6}

The Beam Current Monitor (BCM) is designed for stable, low noise, non-intercepting beam current measurements. It consists of an Unser monitor, two rf cavities, the electronics and a data acquisition system. The cavities and the Unser monitor are enclosed in a box to improve magnetic shielding and temperature stabilization. The box is located 25 m upstream of the target. You can recognize it as a grey object on the stands, about 2 m downstream from where the beam enters the hall.

The DC 200 down-converters and the Unser front end electronics are located in Hall A. The temperature controller, the Unser back end electronics and its calibration current source, cavity's RF unit (housing the RMS-to-DC converter board) and all multi-meters, VME crate and computers are located in Hall A control room.

2.3.1 System Layout

The schematic diagram of the BCM system is presented in figure 2.5.

The Unser monitor is a Parametric Current Transformer designed for non-destructive beam current measurement and providing an absolute reference. The monitor is calibrated by passing a known current through a wire inside the beam pipe and has a nominal output of 4 mV/ μ A. It requires extensive magnetic shielding and temperature stabilization to reduce noise and zero drift. As the Unser monitor's output signal drifts significantly on a time scale of several minutes, it cannot be used to continuously monitor the beam current. However, this drift is measured during the calibration runs (by taking a zero current reading) and removed in calibrating the cavities. The more stable cavities are then used to determine the beam current and charge for each run. We also use the OLO2 Cavity Monitor and the Faraday Cup 2 at the Injector section to provide an absolute reference during calibration runs.

The two resonant rf cavity monitors on either side of the Unser Monitor are stainless steel cylindrical high Q (~ 3000) waveguides which are tuned to the frequency of the beam (1.497 GHz) resulting in voltage levels at their outputs which are proportional to the beam current. Each of the rf output signals from the two cavities are split into two parts. One part of the signal is converted to 10 kHz signals (by the "downconverters") and fed into an RMS-to-DC converter board consisting of a 50 kHz bandpass filter to eliminate noise, amplified and split to two sets of outputs, which after further processing are recorded in the data stream. These two paths to the data stream (leading to the sampled and integrated data) will now be described. (The other part of the split signal is downconverted to 1 MHz signals and represents the old system (pre Jan 99). Only the HAPPEX collaboration presently uses these signals.)

For the sampled (or EPICS or Slow) data, one of the amplifier outputs is sent to a high precision digital AC voltmeter (HP 3458A). Each second this device provides a digital output which represents the RMS average of the input signal during that second.

⁵ CVS revision Id: bcm.tex,v 1.3 2003/06/06 15:19:02 gen Exp

⁶ Authors: A.Saha <mailto:saha@jlab.org>

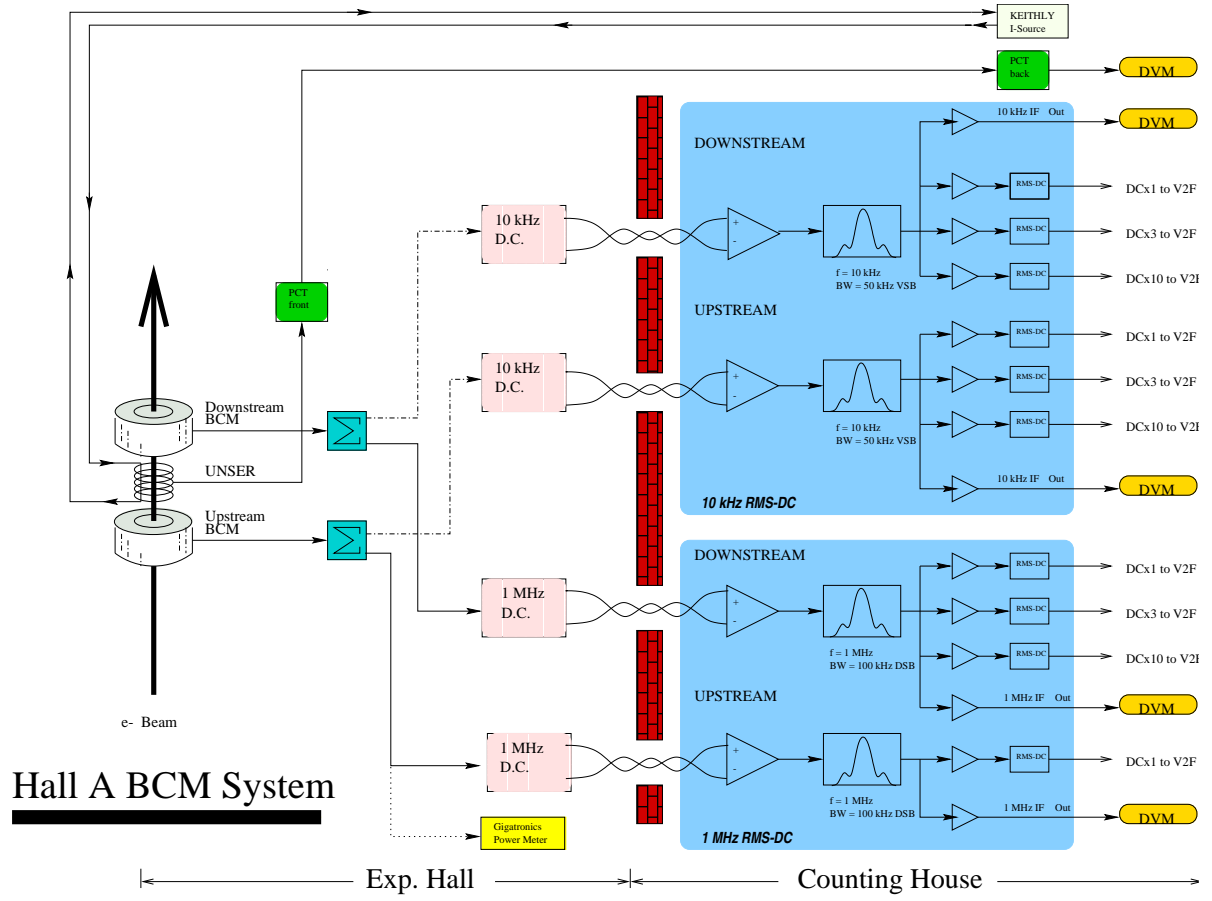


Figure 2.5: Schematic of the Hall A beam current measurement system.

The resulting number is proportional to the beam charge accumulated during the corresponding second (or, equivalently, the average beam current for that second). Signals from both cavity's multi-meters, as well as from the multi-meter connected to the Unser, are transported through GPIB ports to the HAC computer where they are recorded every 1 to 2 seconds via the data-logging process which is described in the calibration procedure. They are also sent through EPICS to CODA and the data stream where they are recorded at quasi-regular intervals, typically every two to five seconds.

For the integrated (or VTOF or Fast) data, the other amplifier output is sent to an RMS-to-DC converter which produces an analog DC voltage level. This level drives a Voltage-To-Frequency (VTOF) converter whose output frequency is proportional to the input DC voltage level. These signals are then fed to Fastbus scalers and are finally injected into the data stream along with the other scaler information. These scalers simply accumulate during the run, resulting in a number which is proportional to the time integrated voltage level and therefore more accurately represents the true integral of the current and hence the total beam charge. The regular RMS to DC output is linear for currents from about $5 \mu\text{A}$ to somewhere well above $200 \mu\text{A}$. Since it is non-linear at the lower currents, we have introduced a set of amplifiers with differing gains (x3 and x10) allowing the non-linear region to be extended to lower currents at the expense of saturation at the very high currents. Hence there are 3 signals coming from each BCM (Up_{x1}, Up_{x3}, Up_{x10}, Dn_{x1}, Dn_{x3}, Dn_{x10}). All 6 signals are fed to scaler inputs of each spectrometer (E-arm and H-arm) . Hence we have a redundancy of 12 scaler outputs for determining the charge during a run. During calibration runs we calibrate each of these scaler outputs.

2.3.2 Authorized Personnel

All Hall A members are authorized to take BCM calibration data using the Standard Non-Invasive Hall A BCM Calibration Procedure. The extended calibration procedures involving the Faraday Cup 2 and the OLO2 monitor at the Injector are presently performed by A. Saha.

The Accelerator AES group performs the maintenance of the BCM monitors. These include:

- | | |
|--|--------------------|
| 1. The Unser calibration. | Every 3 months |
| 2. Resonant Cavities Tuning. | Every Downtime |
| 3. Multi-meters Autocalibration. | Every Downtime |
| 4. Connectors Cleaning. | Every year |
| 5. Unser Keithley Current Source. | Calibration Yearly |
| 6. Digital Multi-meters HP3458A and HP 34401A. | Calibration Yearly |

System Contacts:

Arun Saha -x 7605

Jean-Claude Denard -x 7555

2.4 Arc Energy Measurement ^{7 8}

The ARC energy measurement is under EPICS control through a MEDM display. Two independent control systems are used: the beam bend angle measurement through the arc ("scanners") and the field integral of the arc ("integral"). To measure the energy:

- perform several angle measurements
- perform an integral measurement
- analyze the integral measurement and note the value of the arc field integral
- analyze the angle measurements, average the results (proposed by the software), then ask for the energy calculation, enter the above arc field integral and you will get the beam energy computed from the average angle.

2.4.1 Computers and softwares used by scanners and integral:

	SCANNERS	INTEGRAL
Computer:	hac	pascal1(IP=129.57.188.20)
type:	hp	sun
login under:	gougnaud	gougnaud
password:	see Arun	see Arun
Disk mounted on CUE?	yes (use cp for transfer)	no (use ftp or rcp)
.adl files directory:	~/arc2/adl/	~/EPICS/adl/
standard .adl file:	ARC6.adl	arc_integral.adl (arc_master.adl)
expert .adl file:	expert.adl	arc_nmr.adl (arc_pdi.adl...)
Directive files dir.:	~/arc2/ARC/	~/EPICS/ioc.mg/
standard directive file:	data1234 (data56)	magnet.dir
output file:	~/arc2/ARC/scan_nnn.data	~/EPICS/integral/ integral_nnn.data
analysis code:	~/arc2/ARC/pascal/arc-scan.sun	~/pascal/arc-integral
result file:	~/arc2/ARC/scan_nnn.data.log	
ioc name:	arcioc (IP=129.57.188.24)	arcioc2 (IP=129.57.188.21)
ioc login name:	None	target
ioc password:	None	password
ioc "iam":	gougnaud	gougnaud
ioc type and RAM size:	MVME162, 8Mo	MVME162, 8Mo
ioc boot file:	~/arc2/ioc/up	~/EPICS/ioc.mg/up

⁷ CVS revision Id: arc.tex,v 1.3 2003/06/06 15:19:02 gen Exp

⁸Authors: A.Saha <mailto:saha@jlab.org>

2.4.2 Summary of ARC operations:

Six scanners of the same type, called "ARC scanner" and labelled from scanner #1 to #6, are installed on the Hall-A beamline. Scanners #1 to #4 are used for the ARC energy measurement and they are located on the Hall-A arc: #1 and #2 just upstream of the arc, in the BSY, and #3 and #4 in the Hall-A tunnel, just upstream the Compton polarimeter. Scanners #5 and #6 are located between the Moller and the target to control the beam geometry on the target and their use will not be discussed here.

Each scanner has a motor/ball-screw/shaft-encoder/vacuum-penetrator system moving accurately a set of 3 tungsten wires through the beam. Each time a wire crosses the beam a PMT located a few meters downstream records a signal due to the electromagnetic shower induced by the beam in the wire. Both forward and backward passes are recorded. The motion is a horizontal translation and, for a forward pass:

- the translation is from beam left to beam right,
- the two first wire crossing the beam are at 45deg from the vertical,
- the third wire, which is the only important for the ARC energy measurement, is vertical.

Recording, during the scan, the scanner position and the PMT output voltage allows us to determine the beam position at each scanner location. Then, using calibration data not detailed here, we deduce the net beam bend angle through the arc. This result measured in dispersive arc tuning, along with the field integral of the arc dipoles, provides an accurate determination of the beam energy.

The list of the operations for an ARC energy measurement is given here and will be detailed after:

- 1/check the pulser (scanners)
- 2/check the HV (scanners)
- 3/check EPICS (scanners)
- 4/check space on disk(scanners)
- 5/check the integral (see "Details on integral system check" below)
- 6/ask for chicane off, put target in a safe position, ask $\sim 5\mu\text{A}$ (achromatic)
- 7/perform a scan test in achromatic at $\sim 5\mu\text{A}$ -- > solve the trips -- > final adjustment of gains of scanners #1 and #2 -- > save the last (non saturated) scan
- 8/if everything is OK, ask for dispersive beam $\sim 5\mu\text{A}$
- 9/check dispersive beam:
 - CW $\sim 5\mu\text{A}$
 - Fast Feedback ON
 - Energy Feedback ON \leftarrow important
 - Kresting ON
 - arc's quads and steerers OFF
 - beam stable at entrance and exit (Bscope) (see the test plane of the dispersive mode in MCC)
- 10/perform a scan in dispersive at $\sim 5\mu\text{A}$ (see details below)
- solve the trips

- finish the 4 gains adjustment
- perform and save 3 good scans
- 11/perform a field integral (see details below)
- 12/restore beam for the experiment, unmask the diagnostics, restore achromatic mode and chicane, quit MEDM and turn both HV channels OFF.
- 13/analyze scan data (dispersive only) and integral data.

2.4.3 Preliminary details about MEDM

To fill or update an input field of MEDM, put the mouse cursor in the field, do the edit or change, and then PRESS CARRIAGE RETURN WHILE THE CURSOR IS STILL INSIDE THE FIELD!!!

2.4.4 Details on pulser check

A pulser is used to trigger the scanner acquisition. The ARC scanner's pulse generator (middle counting room) must be adjusted on 1000Hz for CW beam (on "external trigger" in pulsed mode, for any scanner). Check the output with a scope.

Settings for CW mode:

- frequency: 1KHz
- delay: not important in CW, should be always 0.
- time width: 10 μ s
- level: 2.5V on 50 Ω load, 5V on 1 M Ω , polarity: + (TTL).

2.4.5 Details on HV check

The energy measurement uses scanners #1 to #4 with PMT read out. One PMT (PMT0) is in the BSY reading scanners #1 and #2. One other is in the Compton region (PMT1), reading scanners #3 and #4. They both are energized by the "beam line HV module", card#1 channel#0 (PMT0) and channel#1 (PMT1), under EPICS control of the general Hall A control. Both voltages must be -1200V, make sure that "Meas. V" indicates this voltage. If needed, push on "enable/disable" or edit the "SET V" field.

2.4.6 Details on EPICS check (scanners)

-login as "gougnaud" on hac, you need to know the password, ask Arun Saha. If you connect by "cd ~gougnaud", you will not be able to edit the command file nor save the data. hac> cd arc2/adl hac> medm&

- on the medm access window, click on "file", and then "open"
- in the open file window, select "ARC6.adl"; the ARC window must appear then
- on the medm access window, click on "execute"
- if then the ARC window remains partly blank, or if you have some doubt about the identity of the program running in the ioc, go to the "reboot ioc" section below.

2.4.7 Details on ioc reboot (scanners)

Reboot arciooc by pushing the "Beamline Arc Measurement VME Reset" green button (middle counting room): the arciooc is loaded from the "up" file. If the ARC window (in execute mode) was not blank, it becomes blank, then wait for 1 minute and it returns to grey: the scanner is then operational. If the ioc is not dead, you can also reboot it by software through the network:

```
hac>rlogin arciooc
```

```
- > reboot (the rlogin connection is then broken by the reboot)
```

10/98: The hard reboot (green button labelled "ARC") is temporarily connected also to another VME crate (e,p energy measurement), use it only if e,p is not running.

2.4.8 Details on disk space check (scanners)

Run the "quota -v" UNIX command under `~gougnaud/arc2/ARC`:

```
Filesystem usage quota limit timeleft files quota limit timeleft
/u/home 119308 512000 512000 924 -1 -1
```

Do it several times, sometimes the answer is crazy! In the above example you have about 400Mo free, a scan file of scanners #1 to #4 (energy measurement) occupies about 1Mo when unzipped and 300Ko when zipped, so you have room for ~ 400 unzipped files or ~ 1200 zipped files.

2.4.9 Details on running a scan

-On the MEDM screen load "data1234" as Command File. Content of "data1234":

```
+1 P 5.
+2 P 5.
+3 P 5.
+4 P 5.
-1 P 5.
-2 P 5.
-3 P 5.
-4 P 5.
```

means: use scanners #1 to #4, do first the 4 forward pass and then the 4 backward ones (to give the wires time to cool down) at 5 turns/s = 12.500 mm/s. Warning: lower velocity may cause the wire to melt. An error message will be edited if the velocity is outside $]0., 6.1 \text{ t/s}[$. P is for PMT readout (S for Secondary emission for scanners #5 and #6). The file is in `~gougnaud/arc2/ARC`. In pulsed mode (60Hz) use a velocity of 0.3 turn/s. You need to edit a special file setting this velocity. On the MEDM screen update CW/60Hz, beam current and DISPersive/ACHROmatic (for the record).

-Push "START" when ready, you can follow the operations by looking at:

-running command: the line of the "Command file" currently executed

-the cursor position of the scanners

-voltage versus position plot. The location of the 6 scanners on the MEDM window is the following:

#1	#2
#3	#4
#5	#6

The forward plot is green, the backward one is red. In case of saturation, redo the scan with lower gain (see details below). The only peak used for energy measurement is the rightmost one (H profile produced by the V wire): focus on this peak to adjust the gain, the 2 other peaks may saturate.

-the names on the top of the plots are the CEBAF device names of the scanners.

WARNING: operating at too high a beam current or too small a velocity may cause the wire to melt, with no opportunity to repair it before the next shutdown. The total travel time is about 15 s per scanner. During the travel, have a look at the beam current. If the beam trips, inquire why, correct if it was caused by the scan (set masks), and redo the scan (see details on trips below).

-Save the data (see details below).

-Print the MEDM window (see details below).

-you can plot the profile (see details below).

After the scan, check the peak (rightmost) quality: it must be compact (Gauss curve) with a good signal/noise ratio (>5) If scan #1 and #2 are not compact: report to MCC and make sure that the fast feedback is ON. If scan #3 and #4 are not compact: report also to MCC and make sure that the energy feedback and the kresting are ON.

If the scan seems OK: start a field integral measurement and report to "saha@jlab.org"

with as much details as possible (at least the file names) for data analysis and beam energy determination. Record the mail in the e-logbook. Don't forget to save the files.

2.4.10 Details on MEDM window print

To print the MEDM window: put the mouse cursor somewhere in the background part of the ARC window (outside the plots), push the mouse right button, select print, release the button. It should go on "chalhp" if you work from the counting house.

2.4.11 Details on profile plot

To plot the profile: use your favorite curve plotter (hvplot, xmgr...) The scan file is a plain ASCII file with a line per acquisition (trigger) and two float per line: position in encoder unit (4096.0 per 2.500 mm or turn) and voltage after gain in V. First the forward profile with increasing "x", then the backward one, with decreasing "x" (x=coordinate transverse to the beam and horizontal. Towards beam right for scanners #1 to #4, towards beam left for #5 and #6). Some lines are header lines. In this case the 1st character is a "!" seen as a comment line by hvplot (needs to be changed for other

plotters). The rightmost peak (high x values) was produced by the vertical wire (it is a pure horizontal profile), the 2 other peaks by the +45deg. and -45deg. wires.

2.4.12 Details on gain adjustment (scanners)

Adjust the gain of the signal amplifier to get $]-10V, +10V[$ at the input of the ADC, range= 001, 002, 004,...128, 256.

Gain adjustment: in the ARC scanner MEDM window, click (right button for Arun Saha, left one in general!) on the gain command button located close to the plot of the profile of the scanner you want to adjust. Then select a gain and release the mouse.

After a scan:

-Select higher gain if the rightmost peak is $< 3V$ (in absolute value)

-Select lower gain if the scanner saturates. To know if the scanner saturates, do not believe the MEDM plot (on which several adjacent channels are averaged), trust the red diode associated to each scanner (close to the plot). If you want to know what these diodes look like, click on "edit" on the MEDM access window: you will see the diodes. Then return to "execute".

Start with the gains (dispersive case):

scanner	gain
#1	4
#2	8
#3	32
#4	32

Note that in dispersive mode the beam is dispersed at scanners #3 and #4 locations, so these scanners need a higher gain than #1 and #2.

To zoom on a peak, change the MEDM parameters of the window ("edit"):

-first determine the range (in mm) on which you want to zoom

-on the MEDM access window, push on "edit"

-on the ARC window, click anywhere inside the plot you want to change

-on the "Resource Palette", go down to "Axis Data", select it

-on the "Cartesian Plot Axis Data", in the "X Axis" part (X means horizontal), change "Axis Range" from "auto-scale" to "user-specified", then edit "Minimum Value" and "Maximum Value" to specify the horizontal range you want to look at, the unit is mm. If you used the "edit" facility of MEDM, it will suggest that you save the changes when killing the window. Do not save the changes!

-on the MEDM access window, push on "execute"

Short-cut: push on the right button while the cursor is inside the plot, you will access directly to the MEDM axis data menu Other MEDM tricks (may depend on the version of MEDM you are running):

-Control+middle button+vertical drag will scale the plot up or down

-Shift+middle button+drag will translate the plot.

2.4.13 Details on file save (scanners)

To save the data in a disk file: push on "Save". The software builds automatically a name of the type: "scan_nnn.data", where nnn is the scan run number, incremented automatically. The current run number is stored on disk, so unless a disk crashes, you can reboot the VME or delete a data file without resetting this number. Read the run number on the MEDM screen and record the file name in the e-logbook. The file will be stored in ~gougnaud/arc2/ARC. As the file is big (2*7000 channel histogram per scanner), purge or compress your own data files. ~gougnaud belongs both to hac and the CUE, thanks to Javier. So you do not need "ftp" to copy it inside the CUE; the cp command works as far as you have the good file access. Write in the e-logbook the final path of the file in the CUE.

Example of scan file: scan_159.data

```
!version:2
!THU MAY 27 12:55:25 1999
!CW ,CW_60Hz, beam time structure
! 5.000, Microamp, beam current in microamp
!ACHRO,DISPersif_ACHROmatique, arc optics tuning
data1234,Command_Filename
!
!+1 P 1 5. ,Current_Command_Line
!IHA1C07A a,p,TJ_Device_Name
!-1. p,Displacement_X, dimensionless, X=beam left
!0. p,Displacement_Y, dimensionless, Y=top vertical (Z=beam)
!1 ,Rod.Serial_Number
!235360 p,Fiducial_To_Beam_Micron (at survey scanner position)
!1 ,Cartridge_Serial_Number
!81270 a?,p,Cartridge_Range_Micron
!20 ,Wire_Diameter_Micron
!W ,Wire_Material
!3 p,Number_Of_Wire
!20 p,Survey_Wire_Diameter_Micron (Wire used for above data)
!284375,257840,234730 p,Fiducial_To_Wire_Micron
!.707,0,-.5 p,Differential_Fiducial_To_Wire (per micron of wire diam)
!44.97,-45.04,-0.06 p,Angle_Degree (around Z axis, =0 when perp. to displ.)
!0.,0.00315,0. p,Differential_Angle_Degree_Per_Micron (of wire diam)
!4096 a,p,Encoder_Home
!118405 p,Encoder_Survey (Survey of 11 Aug 98)
!1 a?,p,Encoder_Sign (+1 if increase at forward)
!4096 a?,p,Encoder_unit_per_Turn
!10 a?,p,Motor_Micro_Step_Per_Step
```

```

!200 a?,p,Motor_Step_Per_Turn
!2500 a?,p,Screw_Pitch_Micron
!1 a? ,Motor_Polarity (used for forward displacement)
!begin forward 1 Time Stamp (s)=0
4093.0 -0.002
4093.0 0.007
4093.0 0.007
.....
135163.0 -0.002
135163.0 0.002
!end forward 1 Time Stamp (s)=1305473
!-1 P 1 5. ,Current_Command_Line
!begin backward 1 Time Stamp (s)=1305498
135163.0 0.007
135163.0 0.007
.....
4092.0 0.002
4092.0 0.002
!end backward 1 Time Stamp (s)=1305505
!+2 P 2 5. ,Current_Command_Line
!IHA1C07B a?,p,TJ_Device_Name
!-1. p,Displacement_X, dimensionless, X=beam left
!0. p,Displacement_Y, dimensionless, Y=top vertical (Z=beam)
!4 ,Rod_Serial_Number !235120 p,Fiducial_To_Beam_Micron (at survey scanner po-
sition)
!4 ,Cartridge_Serial_Number
!81270 a?,p,Cartridge_Range_Micron
!20 ,Wire_Diameter_Micron
!W ,Wire_Material
!3 p,Number_Of_Wire
!20 p,Survey_Wire_Diameter_Micron (Wire used for above data)
!284310,257775,234665 p,Fiducial_To_Wire_Micron
!.707,0,-.5 p,Differential_Fiducial_To_Wire (per micron of wire diam)
!45.08,-44.96,0. p,Angle_Degree (around Z axis, =0 when perp. to displ.)
!0.,0.00315,0. p,Differential_Angle_Degree_Per_Micron (of wire diam)
!4096 a?,p,Encoder_Home
!118407 p,Encoder_Survey (Survey of 11 Aug 98)
!1 a?,p,Encoder_Sign (+1 if increase at forward)
!4096 a?,p,Encoder_unit_per_Turn
!10 a?,p,Motor_Micro_Step_Per_Step !200 a?,p,Motor_Step_Per_Turn
!2500 a?,p,Screw_Pitch_Micron
!1 a? ,Motor_Polarity (used for forward displacement)
!begin forward 2 Time Stamp (s)=0

```



```

4092.0 -0.007
4092.0 0.017
.....
.....
4090.0 0.032
4090.0 0.129
!end backward 4 Time Stamp (s)=1305529

```

2.4.14 Details on trip handling

Trips are frequent at $5\mu\text{A}$, caused by scanners #3 and #4 and triggered by the Compton ion chamber or BLM, even with chicane OFF. They are invasive for the other halls. If a trip occurs, write in the e-logbook which scanner, forward/backward (for this, you have to monitor the beam current during the scan), beam current, arc tuning mode, which diagnostic tripped (ask MCC), get a strip chart of this diagnostic (MCC). Contact the beamline coordinator (Arun Saha) or the hall leader (Kees de Jager) to allow MCC to mask the diagnostic. But in any case start with unmasked diagnostics to have all safety systems responding. If masking is impossible or not sufficient, reduce the beam current down to $1\mu\text{A}$ but the quality of the energy measurement will then be affected by the poor signal/noise ratio.

If the trip occurred from scanner #3 or #4 during the preliminary test in achromatic mode, leave this step and ask for dispersive mode. In this mode, due to the dispersion of the beam, the luminosity will be reduced and hopefully the trip will not occur. Nevertheless, the test in achromatic mode is useful to check the system (including the trip protection!) and to anticipate a gain change for scanners #1 and #2.

2.4.15 Detail on encoder change (scanner)

The main screw shaft is coupled to the stepper motor by a bellow coupler (bellow #1) and the motor to the encoder by a second bellow coupler (bellow #2). If for any reason (encoder change, motor change, one of the bellows slept) the angular relationship between the screw and the encoder is lost, then:

- these two objects must be linked again in good angular agreement (see detail)
- the theodolite survey of the bench must be redone (see detail)

2.4.16 Detail on encoder re-mount (scanner)

The procedure is based on 2 rules:

- the "home" position is defined by an encoder reading=4096 enc. units
- this "home" position must be at about 1/2 turn ($\sim 2048=1.25\text{mm}$) from the Low Limit Switch (LLS) transition. So this transition must happen at encoder reading ~ 2048 .

-if the Low Limit Switch was also changed, then the rule is that the external fiducial must be at 230mm from the beam nominal axis when the encoder reading is 118407 ("survey" position). This rule needs the help of a survey.

The procedure is the following:

-by software (see "scanner expert task detail") or by hand (by acting on the bellow #1), set the scanner in the convenient position (LLS or survey):

-decouple the bellow #2

-connect the encoder to the control box readout

-by hand turn the encoder shaft up to have a good reading

-strongly fasten the coupler #2 Note: the encoder is absolute over 64 turns with 4096 units per turn. So, starting from 0 and turning it clockwise, one should read:

-4096 after one turn

-8192 after two turns

-...

-up to 262143 just (one puls) before 64 turns

-0 again one puls after.

-4096 after one turn

2.4.17 De tails on scanner expert task

The path of the "expert task" MEDM file is given in the first subsection. Use this task to set the encoder in any position between the limit switches, to dismount the wire cartridge, to set the encoder,...

-Call this task in MEDM.

-You get a small window with a blue button.

-Left click on it: it gives you a choice between the 4 ARC scanners.

-Select the scanner you are interested in, then release the left mouse button.

-An "Expert-task" bigger window appears.

-In this new window, left click on the blue button "click to initialize...".

-Then the designated scanner name is displayed on the top of the window.

-Edit the motion you want in the "First goal" input field. This is an ABSOLUTE position (i.e. not an increment), from an origin which can be arbitrary, in unit of motor micro-step. $+2000 \text{ microstep} = +1 \text{ turn} = +4096 \text{ encoder units}$, so one has 2.048 encoder units per microstep.

-push on "Pos-- >0" to set to zero the "Motor current position" register. The current scanner position becomes the new origin of the motor positions. -once the motor position is entered, push on "1 WAY" to execute the motion

-If you want to move the scanner from its current position by 10mm towards the beam, and if the current position is 100000, then enter $100000 + (10./2.500) \times 2000. = 108000.$, and push on "1 WAY".

-If you want to go to the LLS position, enter a large negative value like -1000000, and push on "1WAY" Note: Limit switches will not stop the motor at a very reproducible position.

2.4.18 Detail on theodolite survey of a bench

The goal is to measure the H angle between the segment joining the fiducials of the 2 scanners of the bench in their "survey" position, and the normal to the autocollimation mirror associated with this bench. The procedure is the same for both benches, except that: -the upstream one needs a BSY access, the downstream one just a Hall A access, providing the light tubes were left in straight position.

- the upstream angle is ~ 0 , only affected by a change in the scanners; the downstream one is ~ 6 deg and it can be affected by a change in the scanners or by a motion of the tunnel.

- the upstream autocollimation is at short distance, the downstream one is at long distance, through the light tubes, and the line of sight is bent by a pair of mirrors, both at forward and at backward pass.

The procedure is:

- using the "expert task" (see detail), set both scanners in their "survey" position (encoder=118407+-2)

- install the theodolite on its support and level it carefully.

- mount the battery (2 autocollimation batteries and chargers are stored in the shed, make sure the batteries are charged)

- push the "ON/Enter" button, the bottom display prompts "V zero 1"

- release the "V" break (small knob of the top pair of knobs)

- initialize the V (Vertical angle) encoder by turning slowly and continuously the optics around the horiz. axis in a direction, until you get a beep and "V zero 2" displayed. Then turn in the opposite direction, until you get a beep and "A zero" displayed in the top display.

- release the "A" break (small knob of the bottom pair of knobs)

- initialize the A (Horizontal angle) encoder by turning slowly and continuously the whole theodolite around its vertical axis, until you get a beep and "Theo" displayed in the top display. Push "ON/Enter" button to accept the proposed "theodolite" menu.

- from this point, "V" and "A" angles will be permanently displayed in their own displays, in units of decimal degrees from 0.0000 to 359.9999. If the decimal part is not displayed, correct the levelling.

Note: the origin of the A angles is arbitrary (this is not the case for the V angles), so you may decide to set it to zero, for example at the first autocollimation measurement: this way, the measured angles will be more intuitive. To do this:

- from the "THEOD" menu push on "+" (means go to the next menu called "SET A")

- "SET A" menu is proposed: push "enter" to accept, you have a "WAIT" displayed, after which the angles are displayed again, but with A=0.0000.

- push "-" to proceed: the sub-menu "MEAS P" is proposed, you must accept ("enter"), you have then the angles displayed, push "-" to come back to the "THEOD" menu, then push "enter" to accept it, you should still have A=0.0000: you have a new origin of the A angles.

- measure the autocollimation angle:
- open the light tube
- plug the autocollimation light cable
- turn ON the autocollimation power switch on the battery
- adjust the autocollimation power potentiometer to half range
- remove the theodolite handle, to let the cable go through.
- adjust the ocular (small knob on the optics) to your vision, until you have the cross hairs well focused
- adjust the main focusing (large knob on the optics) to infinity (turn counter clockwise up to the limit and come back by $\sim 1/4$ turn)
- adjust the V angle to 90.00?? deg.: first move the optics, second fasten the V break and use the V knob.
- adjust the A angle to point in the direction of the light tube: first move the theodolite, second fasten the A break and use the A knob.
- using the A knob, search for a light signal
- focus on it (main focusing): the autocollimation pattern is a yellow/green cross
- adjust A and V angles to get the cross hairs on the autocollimation cross, fine adjust both focusings, then check if the pattern you have is the good one (there are 2 wrong autocollimation patterns): when you change by a small amount the A/V angle, then the A/V coincidence between both crosses must be destroyed. If it is not the case, you are focusing on one of the two wrong patterns. Then change the main focusing towards infinity (counter clockwise) to get another pattern.
- fine adjust the autocollimation power potentiometer to get the best vertical line of the autocollimation cross -fine adjust A and V angles, record their values in the Shed logbook.
- change both angles by 180.000 deg., WITHOUT CHANGING THE MAIN FOCUSING, and redo the previous step.
- close the light tube
- turn OFF the autocollimation power switch on the battery, Note: the above measurement is easy from upstream, more tricky from downstream (long distance autocollimation). New operators should start with the upstream measurement.
- measure the scanner #2/#3 (the one which is on the autocollimation side)
- remove the scanner cover -unplug the connexion of the encoder to the VME -plug the control box on the fiducial lamp and on the encoder
- record the encoder reading in the logbook. It should be $\sim 118407 \pm 2$
- adjust the main focusing on the fiducial wire
- adjust the V angle to the middle of the aperture across which the wire appears -fine adjust the A angle, record A and V values in the Shed logbook.
- change both angles by 180.000 deg., WITHOUT CHANGING THE MAIN FOCUSING, and redo the previous step.
- record the encoder reading in the logbook. It should give the previous reading ± 1 encoder unit
- unplug the control box

- plug the connexion of the encoder to the VME
- cover the scanner, Note: in case of scanner #2, a foil closing the apertures in the mirror support must be removed prior to the survey, and reinstalled after.
- measure the scanner #1/#4 as for #2/#3
- re-measure the autocollimation angle.
- turn OFF the theodolite (push simultaneously the + and - buttons)
- release both breaks
- mount the handle
- dismount the theodolite
- dismount the battery and the autocollimation cable
- store the theodolite in its box
- store the theodolite box and the control box in the Shed
- charge the battery(ies)

Note: in case you have to change the battery during the measurement, redo the complete measurement with the new battery. A battery in good shape can provide ~ 2 h of work with autocollimation ON. The survey of a bench will take between 1h and 1/2h. If possible, discharge the battery before charging it.

- analyze the angle:
 - in the directory `~gougnaud/arc2/ARC/angles`, edit a plain ASCII file named `upstream.ddmmyy.dat` or `downstream.ddmmyy.dat`, depending on the bench, where `ddmmyy` stands for the date of the survey. Use `upstream_270798.dat` or `downstream_270798.dat` as a model. Units are encoder unit and decimal degrees. If several measurements of the same quantity were done, enter the average. If the full measurement of a bench was done twice, edit both sets of data as in the model.
- run "angle" on a Sun machine and follow the instructions of the program, accept the proposed mirror calibration angle and ask for an average of all your measurements. If only one bench was measured (encoder change, BSY closed,...), use for the other bench the most recent file available in `~gougnaud/arc2/ARC/angles`.
- analyze individual measurements and compare them to the above average. The reproducibility of the reference angle measures several times on the same day should be $\leq 10^{-3}$ deg (17 urad $\sim 3 \cdot 10^{-5}$ on the energy).
- compare the new average to the previous one: if nothing changed in the scanners, and if only the downstream angle changed, this can be interpreted as a motion of the arc (the code gives the detail of the 3 angles: upstream, downstream and reference).
- the files used today (01/07/99) are `upstream.250699.dat` (1 meas.) and `downstream.250699.dat` (2 meas.). They result in a reference angle of 34.32322 deg. (averaged)
- write the new reference angle in the arc-scan source code (include file "arc-incl-plot.f", parameter "Reference_Angle_Degree")
- compile and test the arc-scan code.
- report in the e-logbook about the changes and results (file names).

Example of upstream file: upstream_250699.dat (1 meas.)

UPSTREAM BENCH MEASUREMENT

Used unit: decimal degrees

Enter data in this order:

- - Autocollimation
 - - Fiducial upstream of upstream bench #1
 - - Fiducial downstream of upstream bench #2
- Horizontal Distance (point A, up. fiducial)= 1996.00 mm #1
 - Horizontal Distance (point A, down. fiducial)= 1975.00 mm #2

25/06/99 Andrew+Tim Mesur. Nb 1

First measurement on 25/06

Encoder reading for upstream scanner of upstream bench: 118406 #1

Encoder reading for downstream scanner of upstream bench: 118406 #2

H1	H2	V1	V2	
0.000100	179.995500	90.002100	270.003500	Autocoll.
359.977700	179.973900	250.509900	109.498800	#1
179.970000	359.967100	250.382500	109.619700	#2

Example of downstream file: downstream_210699.dat (2 meas.)

DOWNSTREAM BENCH MEASUREMENT

Used unit: decimal degrees

Enter data in this order:

- Autocollimation
 - Fiducial upstream of down. bench #3
 - Fiducial downstream of down. bench #4
- Horizontal Distance (point A, up. fiducial)= 1870.00 mm #3
 - Horizontal Distance (point A, down. fiducial)= 1840.00 mm #4

21/06/99 Pascal Mesur. Nb 1

First measurement on 21/06

Encoder reading for upstream scanner of downstream bench: 118405 #3

Encoder reading for downstream scanner of down. bench: 118408 #4

H1	H2	V1	V2	
0.000100	179.998050	90.001400	270.000000	Autocoll
6.100100	186.10110	110.667500	249.336900	#3
6.176100	186.175700	249.129900	110.876300	#4

21/06/99 Pascal Mesur. Nb 2

Second measurement on 21/06

Encoder reading for upstream scanner of downstream bench: 118405 #3

Encoder reading for downstream scanner of down. bench: 118408 #4

H1	H2	V1	V2	
0.000100	179.998100	90.003800	270.003000	Autocoll.
6.100800	186.100400	110.667600	249.338500	#3
6.176000	186.176100	249.130700	110.875600	#4

2.4.19 More on the theodolite menu

It is a 2-level menu, the entry point after power ON and indexes initialization is at the 2nd level (Theodolite ?), the +/- buttons are used to navigate among several choices, the "enter" button to validate the currently proposed choice. In the above list, "+" will move to the next option (down), "-" to the previous one (up), and "enter" will answer "yes" to the proposition. In some cases (SET A) the choice is just yes/no. Then "enter" means "yes" and "+" or "-" means "no":

1st level menu:

- - - - > M (Measure)?
- A (Adjust)?
- U (Unit)?

2nd level menu M (Measure):

- - - - > M-0 Return to 1st level?
- M-2 THEODOLITE? - - - > theodolite
- M-5 Zero angle? - - - > A=0, Set angle? - - - > Set A to value
- M-7 Hold angle? - - - > Hold angle

2nd level menu A (Adjust):

- -- > A-0 Return to 1st level?
- A-1 Adjust V index?--- >Adjust V index
- A-2 Adjust A coll.?-- >Adjust A coll.
- A-4 Illumin. ON/OFF?-- >Change Illumin. mode?
- A-5 Compensator ON/OFF?-- >Change Compens. mode?
- A-6 Levelling with compensation ?-- >Levelling

2nd level menu U (Unit):

- --- > U-0 Return to 1st level?
- U-1 Reverse A reading?--- >Reverse A reading
- U-2 Change V display?-- >Select this V display?
- U-3 Change angle unit?-- >Sel. this angle unit?
- U-7 Sound ON/OFF?-- >Change Sound mode?
- U-8 Select configuration?-- >Select this configur?

2.4.20 Summary of field integral

The purpose is to measure absolutely the straight field integral of a "BA" 3m long dipole, called the "9th dipole" and located in the "Dipole Shed". It is of the same type as the 8 arc dipoles and is powered in series with them.

The ARC integral setup is basically made of a 3m long plate (the "probe") which is able to move inside the 9th dipole gap along the beam axis and carrying two field measurement devices: a pair of pick-up coils connected in series and a set of NMR probes. The coils are on both ends of the probe and the NMRs close to the center.

-at the "upstream" probe position, the "downstream" coil is close to the dipole center, the "upstream" is outside the dipole and the NMRs at one end of the dipole:

```
Door< -- .....< -----DIPOLE----- -- -- >
.....< -----PROBE----- -- -- >
```

-at the "central" probe position, each coil is at one end of the 3m long dipole and the NMRs close to the dipole center:

```
Door< -- .....< -----DIPOLE----- -- -- -- >
.....< -----PROBE----- -- -- -- >
```

-at the "downstream" probe position, the "upstream" coil is close to the dipole center, the "downstream" is outside the dipole and the NMRs at one end of the dipole:

Door< --< -----DIPOLE----- -- -->
< -----PROBE----- -- -->

We call upstream the position where the probe is the closest to the shed access door. Among the 3 above positions, the only one where the NMR can lock on the dipole field is the central one as in the extreme position of the probe, the field homogeneity is not sufficient. The probe position is controlled by a linear encoder. The Z axis refers to the "beam" direction, increasing from upstream to downstream. We use three kinds of "Z":

-Zm to locate a point inside the magnet. The dipole center is at Zm=0 and the yoke ends at +1500.mm

-Zp to locate a point inside the probe. The probe center is at Zp=0. Each of the 4 NMR probes has a Zp given in the file "magnet.dir". At a temperature of 21C, the coils are at Zp=+-1519.815mm (from magnet.dir)

-Zd to refer to a displacement of the probe w.r.t. the dipole. Zd=0 refers to the upstream (home) position of the probe. The integral measurement is performed from Zd=0.000mm (1st PDI trigger) to Zd=3199.000mm (last PDI trigger), for forward pass. Zd is given by the display (at the top of the rack) or by the master screen ("OUT").

The relationship between Zm, Zp and Zd is:

$$Zd - Zm + Zp = C$$

where C is a constant given in magnet.dir (C=1604.000 nomin.). Example of use: to have the probe center at the dipole center, one must set Zd=1604.000mm (set Zm=0 and Zp=0 in the above formula, and solve for Zd)

The integral measurement sequence is the following:

-from the current position (a priori arbitrary) move the probe upstream, up to a limit (optic) switch.

-move downstream by a few mm to cross the encoder index (encoder initialization)

-move to the central position to measure the central field by NMR, the system checks if the NMR locks and if the reading is stable, it will be the "before" field

-move back to upstream position

-move to downstream position while integrating the flux through the coil system, this measurement will be called the "forward" integral (duration ~ 7s)

-move back to upstream position while integrating the flux through the coil system, this measurement will be called the "backward" integral (duration ~7s)

-move to the central position to measure the central field by NMR, the system checks if the NMR locks and if the reading is stable, it will be the "after" field.

In addition to the central field, 4 probe temperatures, a local excitation current measurement, the setting of the dipoles P.S, the readback of the dipoles P.S and the probe position at NMR measurement time are recorded "before" and "after".

To perform an integral field measurement:

1-check if the system works (see "details on integral system check" below)

2-run the above integral sequence (see "details on integral run" below)

3-fix the error(s) if any (see "details on integral errors" below)

4-save the data in a file (see "details on integral data save" below)

5-analyze the data (see Arun Saha).

2.4.21 Shed access and safety

For safety reasons, the access to the shed is limited to authorized persons which are listed in the ESAD. To be added to the list, ask the Hall-A leader. The standard operation mode of the integral measurement setup is the remote mode, through the network, from the counting house. In case of problem needing an access in the shed, unauthorized users must contact Arun Saha.

2.4.22 Details on integral system check

First - from any workstation or X-terminal connected by telnet to pascal1 workstation, run MEDM with arc_master.adl data file (see Arun for the password of gougnaud on pascal1 and the first subsection for the path of arc_master.adl). If pascal1 is not responding, go in the shed and check UPS (see "Details on AC power (integral)" below). If the UPS is not beeping, check the room temperature. If the temperature is above 35C, the thermal protection of the workstation is probably activated, see "detail on temperatures" below. If the temperature is below 35C, ask the computer center to restart pascal1.

Second - check if the 4 temperatures and the 3 currents are stable, in agreement between them and if the beam energy computed from the current is realistic compared to what you know from MCC. In not, call Arun. If the IOC is dead (all displays on "arc-master.adl" are blank), reboot the ioc (see "integral ioc reboot" below) Note: the current/field ratio is about 1000A/1.98T and the energy/field ratio is 12.03 GeV/T. The current used by MCC for the accelerator tuning is the set current. The readback can be different from the set by 0.1A. The local current can be different from the set by 5A. For the temperatures see "detail on temperatures" below.

Third - check if the NMR is locked. If not see "details on NMR lock" below,

Forth - check if the NMR reading is stable within 10-5 relative (P.S. stability). If not, inquire about a recent or running setting change by the MCC. If necessary call Arun Saha.

2.4.23 Details on NMR lock

-check if the dipole current is above 22A. The integral setup can't work for lower currents ($22A \sim .043T \sim 517MeV$), due to the NMR probe limitation.

-check if the probe is at a central position, corresponding to $Z_d \sim 1604mm$. It should be at this position if no special motion was ordered since the previous integral measurement. If not, enter 1604 RETURN in the "set Z_d position" input field, wait for the end of the motion (look at cursor and position readback labelled "out") and wait for the NMR lock for up to 1 minute. Note: due to the software, the position readback may be updated ~ 10 seconds after the real probe motion. $Z_d \sim 0mm$ is for the upstream position, $\sim 1604mm$ for the central position and $\sim 3208mm$ for the downstream position. If the probe does not obey, call Arun. If Arun is not available, reboot the ioc (see "integral ioc reboot" below)

-check if the NMR probe selected is the good one. The system has 4 probes to cover the field/energy range [0.043T/0.517GeV,1.05T/12.63GeV]. The software selects automatically the probe from an estimated field and the following range table (from file "magnet.dir"):

mini	maxi	probe
T	T	
0.043	0.1254	# 1
0.1250	0.250	# 2
0.177	0.470	# 3
0.338	1.06	# 4

The estimated field is computed from the "set" current and the coefficients given above. Note that there is an overlap between the range of each probe. In the standard mode ("auto selection"), two selection algorithms are used:

-initial selection: select the probe in which the estimated field will be the most "centred"

-routine check: change the probe only if the estimated field is outside the selected probe range.

Initial selection is executed at boot time, at each integral start and when you leave the "manual selection" optional mode.

The routine check is performed periodically.

In some cases in the past this algorithm did not select the best probe. If it occurs again, force the probe selection by opening arc_nmr.adl medm screen, then switch to manual selection mode, click on the probe you want to select and wait for NMR lock. Don't forget to return to the "auto selection" mode before leaving the integral measurement. Report about the problem in the e-logbook.

-expert users can also use nonstandard search modes and DAC values as proposed by the arc_nmr.adl screen ("Dac Value", "Dac+-5%" and "All Probes Range"). Note that "Dac Value" needs a scope. They are asked to restore the standard mode ("SeLected Probe Range") at the end. The DAC to field relationship used by the software is linearly interpolated in the table (from file "magnet.dir"):

dac=0	dac=1000	dac=2000	dac=3000	dac=4095	Probe
T	T	T	T	T	
.040362	.05388	.07443	.104184	.132404	# 1
.080713	.107771	.148845	.208340	.264790	# 2
.161430	.215539	.297680	.416680	.529570	# 3
.322870	.431112	.595471	.833455	1.059210	# 4

Note: as the 9th dipole has a uniform field, there is no gradient coil around the probes and the lock is in general easier to obtain than with the HRS dipoles. Nevertheless some difficulties may occur at low field due to the hysteresis gradient. The NMR system is the same as for the HRS (Metrolab) but the EPICS implementation is different. The

field polarity is "+". Some lock problems may appear in the [60A,70A] range. In this case select the "Dac+-5%" option, compute the approximate field as explained above, estimate the corresponding DAC value from the table above (depending on field value and probe #), set this estimated value in the arc_nmr.adl screen, correct this setting by using the "+", "++", "-", and "--" buttons up to have the "OUT IN T" value close to the field you computed, and then wait for the lock. It should work, you have 100s to get the lock at the beginning and at the end of the integral sequence! The best is to get the lock by this way before starting the integral sequence.

2.4.24 Details on integral run

To run the integral measurement sequence, call the "arc_integral.adl" medm screen on pascal1 (see "Details on integral system check" above), then:

- push "start" to start the full sequence
- look at the results displayed:
- after the "before" NMR measurement: the "before" data set
- after the "forward" integral pass: the forward velocity profile and the forward voltage-after-gain profile
- after the "backward" integral pass: the backward velocity profile and the backward voltage-after-gain profile
- after the "after" NMR measurement: the "after" data set
- if "BAD NMR" or "PDI saturation" flags are set, or if something is obviously wrong in the data or plots, fix the problem (see "Details on integral error" below) and start a new integral run.
- data are ready to be saved (see "Details on integral data save" below)

2.4.25 Details on integral error

- "BAD NMR" flag is set if at least one of the 4 NMR status (locked and stable, before and after) is wrong

- the full NMR field measurement is made of 3 successive elementary measurements separated by a 5s delay.

- the "lock" status is set to wrong if at least one of the 3 NMR measurements did not lock before a 100s timeout. The measurement sequence is aborted as soon as a measurement does not lock, so the maximum time one has to wait for a full NMR measurement is about 100s (in case of a zero current measurement for example)

- the "stable" status is set to wrong if the 2nd or the 3rd field values differs from the 1st by more than 5 10^{-4} relative. In any case, the field value returned is the last one.

- "In position" is set to false if the probe position was outside 1604.0+-0.1mm at NMR measurement time.

- "PDI saturation": the PDI (Mertolab's Precision Digital Integrator) consists in a programmable amplifier and a VFC integrator working in the [-5V, +5V] input range. The PDI gain is the result of an automatic selection in the [1,2,5,10,...1000] range, similar

to the NMR probe selection. In case of a wrong gain selection (maximum voltage after gain, as plotted in the MEDM screen, outside the [1.5V,5V[range), call the "arc_pdi.adl" MEDM screen to switch the gain selection mode from "auto" to "manual" and then select manually the gain. Return to "auto" mode before leaving the integral measurement.

- "before" and "after" data must be very close: < 0.1 C difference for the temperatures of a given probe, ± 0.1 A for the currents and $\pm 10^{-5}$ for the field.

- plots: the blue curves are from forward pass, yellow ones for backward pass.

- the top plot gives the probe velocity (in m/s) as function of its position (in mm). The forward velocity should be $+0.6$ m/s everywhere except at the center where it is reduced to $+0.06$ m/s. The backward velocity plot should be the mirror image of the forward ones (-0.6 and -0.06 m/s)

- the bottom plot gives the coil voltage after gain (in V) as function of the probe position (in mm). It should be a null voltage everywhere except a set of oscillation at the center. The backward voltage plot should be the mirror image of the forward one ($V \rightarrow -V$). See "PDI saturation" above.

- to zoom a MEDM plot, see "Details on gain adjustment (scanners)" above.

2.4.26 Details on integral data save

The procedure to save the datafile from "arc-integral.adl" is the same as for the scanners (see "Details on file save (scanners)" above), with an independent integral run number. The file name will be of the type "integral-nnn.data", stored on pascal1 in \sim gougnaud/EPICS/integral/. As pascal1 disk is not mounted on the CUE, use ftp or rcp to move the file to the CUE.

The size of a file is 207Ko.

The data file is made of:

- a header containing basically the "before" and "after" data
- the forward integral data
- the backward integral data.

Forward and backward integral data are made of 3200 lines of 3 data each:

- a line per trigger, i.e. per mm of probe motion over the 3.2m of the total motion.

The first trigger line is missing.

- the first data of the line is the probe position in mm, which should be a round value from 1.000mm to 3199.000mm at forward pass and from 3199.000mm to 1.000mm at backward pass,

- the 2nd data are the flux increment measured during the current step (i.e. between the previous trigger and the current one) in unit of 10-8Vs, corrected from the gain.

- the 3rd data are the time of the trigger since the start, in microsecond units.

These field increments, like the scan profiles, can be plotted by standard plotters, see "Details on profile plot" above. The curve plotted online in "arc-integral.adl" is the time derivative of the above flux data, multiplied by the gain to get the input VFC voltage after gain.

Example of an integral file:

```
!ARC magnetic measurement integral data file
!version:1
!date: THU MAY 27 15:28:09 1999 THU MAY 27 15:29:21 1999
!local current (A) 142.25 142.25
!remote current set (A) 140.11 140.11
!remote current readout (A) 140.15 140.14
!NMR field (T) 0.2752619 0.2752621 !NMR locked? T T
!NMR stable? T T
!NMR in position? T T
!Zd plate position (mm) 1604.003 1604.003
!temperature x+,z+(deg.C) 33.2 33.1
!temperature x+,z-(deg.C) 32.8 32.7
!temperature x-,z+(deg.C) 31.1 31.1
!temperature x-,z-(deg.C) 31.1 31.1
!PDI gain: 10
!NMR probe: 3
!forward data:
1.000 -100 5138
2.000 200 9695
3.000 -100 13830
4.000 150 17611
5.000 0 21096
6.000 200 24340
.....
3198.000 -100 7051626
3199.000 150 7058284
!end forward, start backward
3199.000 -50 5160
3198.000 -50 9730
.....
2.000 -100 7052428
1.000 -50 7059066
!end backward
```

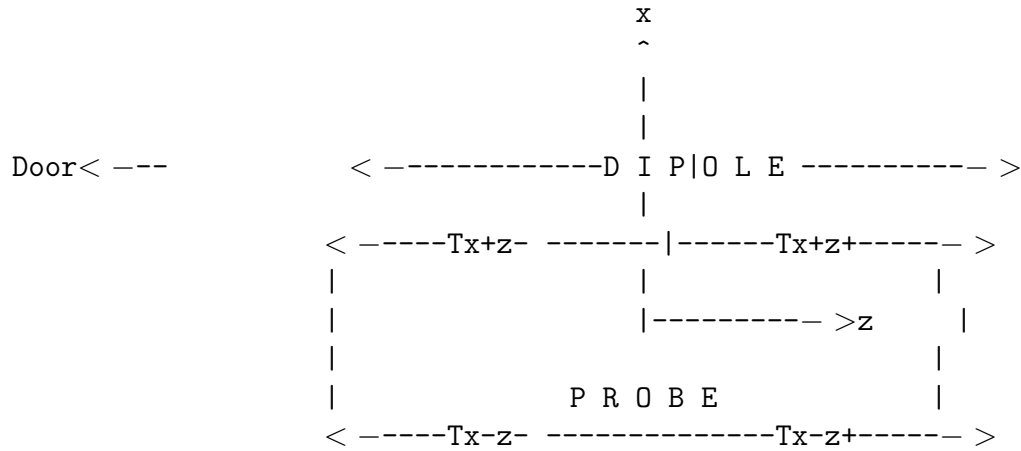
2.4.27 Integral ioc reboot

One of the VME boards (PMAC's motor board) has its own internal boot process triggered at "power on" time. So the usual boot procedure (red push button on the ioc or reboot command through the network) is not sufficient to make sure that the integral VME is correctly initialized. Thus, boot the VME by switching the AC power of the

VME crate OFF and ON. The AC power switch is located in the lower part of the crate front panel.

2.4.28 Details on temperatures

The AC system of the shed is made of two cooling units, a heating unit and a controller connected to two temperature sensors : one located in the shed and one located in the BSY. This system is programmed in such a way that the temperature of the shed follows the BSY temperature within $\pm 2^\circ\text{C}$. The BSY temperature can be anywhere in the $[18^\circ\text{C}, 35^\circ\text{C}]$ range, regardless of the season. The BSY temperature and the shed temperature are given (in $^\circ\text{F}$) by a display panel located close to the workstation, on the wall. The AC system can be set in manual control by turning from "auto" to "manual" a set of switches controlling the cooling units and the heater unit. These switch boxes are located on the shed wall. If the shed temperature is above 34.4°C (94°F), call Arun Saha (the electronics can be damaged) and cool down the shed in manual AC mode. The 4 temperature sensors of the probe are labelled $\text{Tx}+\text{z}+$, $\text{Tx}+\text{z}-$, $\text{Tx}-\text{z}+$, $\text{Tx}-\text{z}-$ depending on their position w.r.t. the following (x,z) frame:



Both "x+" sensors are on the probe edge which is inside the dipole gap and both "x-" sensors on the opposite edge which is outside the dipole gap. Both "z-" sensors are at $1/4$ of the long dimension of the probe and both $z+$ at $3/4$ of this length. The average of the 4 temperatures is used by the analysis program to correct the coil distance from the thermal expansion of the probe, so it is important to make sure that the 4 sensors are working well. The user can just make sure that the temperatures displayed in "arc-master.adl" or recorded in "arc-integral.adl" are realistic. In "arc-integral.adl" they are given in the order: $\text{Tx}+\text{z}-$, $\text{Tx}+\text{z}+$, $\text{Tx}-\text{z}-$, $\text{Tx}-\text{z}+$. $\text{Tx}-\text{z}-$ and $\text{Tx}-\text{z}+$ should be close to the shed temperature. $\text{Tx}+\text{z}-$ and $\text{Tx}+\text{z}+$ depend on the probe position, as the gap (iron yoke) is warmer than the shed and the dipole coil (at both ends of the dipole) is warmer than the iron yoke. For a probe in a central position for more than about one hour, the $\text{Tx}+\text{z}-$ and $\text{Tx}+\text{z}+$ sensors should give the yoke temperature, i.e. the shed temperature plus 0. to 5°C , depending on the current, LCW temperature and

the magnet/shed temperature history. The 4 temperatures are also displayed inside the shed, on the electronics rack. These values are digitized by separate ADCs, so they may differ from the remote values by $\sim 0.1^\circ\text{C}$.

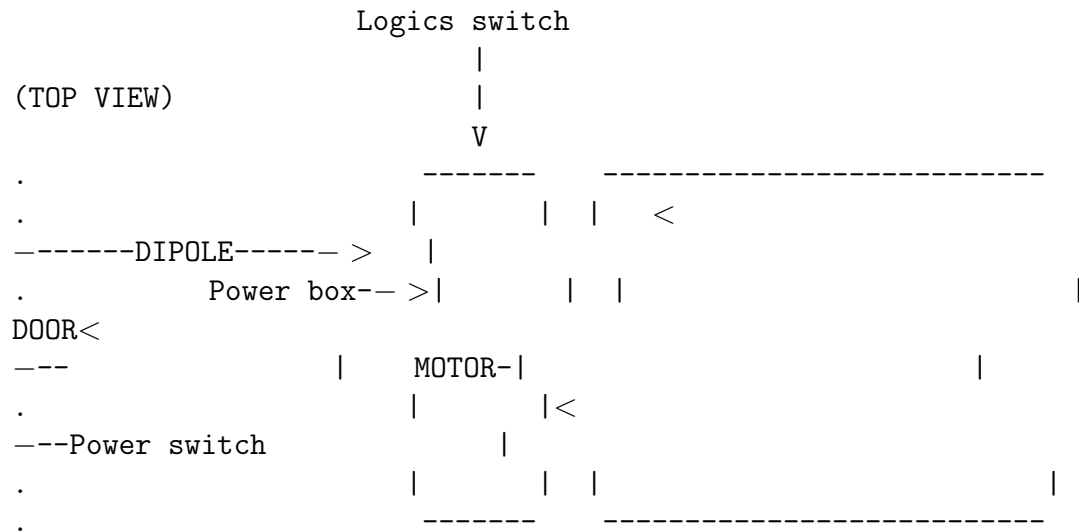
2.4.29 Details on AC power (integral)

All the shed electronics and computer (except the motor power, see details about the Power Switch below) are powered through a UPS (Uninterruptible Power Supply) whose role is to protect the setup from short ($\sim 1/4$ h) power outages and to convert the US AC power (60Hz, 200V between two phases) in a well stabilized AC power of European type (220V, 50Hz). When working in the shed, be careful about the electrical hazard as the setup can remain powered a long time after interrupting the UPS input (see "Shed access and safety" above).

The UPS unit is located under a table, in front of the electronics rack. It has a display, a small keyboard and a beeper. The beeper activated means that some important message about the UPS is displayed. In this case, use the keys to scan the UPS memory, read the messages, record them in the e-logbook, stop the beeper and inform Arun. Refer to the UPS manual (available in the shed) for details of operation.

2.4.30 Details on mechanics (integral)

The probe is capable of a fast motion ($\sim 1\text{m/s}$) and it is hazardous to access or to introduce something inside the device, under the altuglass covers, or to dismount a cover. It is also hazardous to manipulate the motor shaft (see "Shed access and safety" above). To do it safely, the user must first turn off the motor power box. The power box is located under the motor. It has two external switches: one controlling the logics and one controlling the power:



It is important NOT to switch off the logics (some data in memory will be lost), but to switch off the motor power (see the exact Power switch location above) prior to any intervention on the mechanics. The detailed procedure is the following:

- turn OFF the power switch
- wait for ~ 1 min to empty its buffer-capacitor
- you can work safely on the mechanics
- make sure that the path of the probe is free (tools...) and the covers are in position
- turn the power switch back ON
- reboot the VME (see "Integral ioc reboot" above)

The above procedure may be necessary if, for some reason, the probe went outside its allowed range limited by a pair of electric limit switches. The probe range is limited by the following set of devices:

- upstream energy damper for Zd in $[-40., -14.]$ mm
- upstream electric limit switch for $Zd < -7.5$ mm
- upstream optic limit switch for $Zd < -3.8$ mm
(operation range, 3.2m long)
- downstream optic limit switch for $Zd \geq 3200.8$ mm
- downstream electric limit switch for $Zd \geq 3212.3$ mm
- downstream energy damper for Zd in $[3214., 3238.]$ mm

The current status of the 4 limit switches is given in the "arc-master.adl" screen. Optical limit switches are used for the encoder initialization procedure (see "Summary of field integral" above). Electric limit switches should never be activated. But if this happens, then the motor control:

- stops the motor
- raises an error flag (the lettered "d" for defect is displayed inside the power box, the usual display being a vertical segment)
- waits for a manual repositioning of the probe inside its allowed range and for a reboot of the VME.

The manual repositioning of the probe inside its allowed range can be done safely by manipulating the motor shaft while the motor power is off, according to the above procedure.

2.4.31 Details on detailed field mapping

The main use of the integral setup is to measure the integral of the 9th dipole along a straight line, located on the axis of the pole tips. By moving (manually) the dipole in the transverse direction and then performing the integral sequence, one will measure the integral along different axes, and hence extract the gradient of the dipole integral (used to determine the dipole positioning tolerances). By inserting a jumper (short) on one of the pick-up coils and reducing the gain of the PDI, the same sequence as for the integral will provide, after a specific analysis, the field profile of the dipole as seen by the other coil. This profile will cover one half of the magnet, including one of the two fringing fields. Reduce the PDI gain by one step (example: if the automatic gain is 10,

select manually 5) By inserting the jumper on the other coil, one can get the other half profile. These two single coil measurements will provide together the complete profile of the dipole including both fringing fields. For the central part, where the field is uniform, more accurate data can be taken using the NMR probes. Here, there is no change in the hardware, but one must use a specific software: the "mapping" MEDM window. By combining, for a set of transverse positions:

- standard integral measurement
- upstream profile (upstream coil alone)
- downstream profile (downstream coil alone)
- NMR map of the plateau,

one gets a 2D map of the dipole field in its mid-plane with an optimum accuracy and redundancy and a minimum time spent by the operator. This 2D map is used to get the straight-to-curved correction to the integral and a set of tolerances.

Call "medmMew" (and NOT "medm"), then open "arc_map.adl", as this display is written in a new version of MEDM. Due to a bug in this Solaris/MEDM combination, you must enter the name of the display in the open menu, you can't just click on the display file name. You then get the "ARC-MAPPING" screen. You must define the position inside the magnet (Z_m) where you want to measure the field, inside the [-1500mm,+1500mm] range. The software will compute the probe position Z_d depending on the NMR probe selected (automatic or manual selection). You have to define 3 regions, where the steps may differ. Edit the fields:

- STARTING Z_m
- region 1 : NUMBER OF STEPS and STEP SIZE, then the intermediate position Z_m is computed automatically by the software as a result of the above input
- region 2 : NUMBER OF STEPS and STEP SIZE, then the intermediate position Z_m is computed as above
- region 3 : NUMBER OF STEPS and STEP SIZE, then the final position Z_m is computed as above.

Then push "Start". It takes about 20s per point, unless there is a lock problem, where it can take up to 100s (timeout). If the NMR does not lock even far from the ends, push "Stop Map here", use the DAC+/-5% lock mode (see "detail on NMR lock"), and start a new map.

Note: after "Stop Map here" the incomplete map can still be saved. Use "Stop" in case of emergency, and then reboot the VME (see detail).

The measured fields are displayed on the screen as a function of Z_m . The sequence is:

- a measurement at $Z_m=0$, called "Bref1"
- the list of measurement you entered
- a measurement at $Z_m=0$, called "Bref2".

When done, save the data by pushing "Save". The file is numbered automatically, the name is of the type mapping_nnn.data, where "nnn" stands for the map number. The directory is given by the MEDM screen. An example of file ("mapping_7.data") is given below (EPICS was not responding for the P.S. readback and set, the real current

was 90A):

```
!ARC magnetic measurement mapping data file
!version:1
!date: SAT JUN 12 04:49:40 1999 SAT JUN 12 05:41:32 1999
-1460.00 50 20.00
-460.00 46 20.00
460.00 50 20.00
!temperature x+,z+(deg.C) 29.8 30.2
!temperature x+,z-(deg.C) 31.7 32.0
!temperature x-,z+(deg.C) 28.4 28.2
!temperature x-,z-(deg.C) 28.6 28.2
!tal nbr pts: 146
!initial & final NMR probe: 2 2
Zm (mm), B (T), NMR lckd, NMR flag,local crt(Vadc),crt set(A),crt rdt(A)
0.00 0.1770036 1 1 92.19 0.04 0.00
-1460.00 0.1770068 1 1 92.19 0.04 0.00
-1440.00 0.1770157 1 1 92.19 0.04 0.00
.....
1439.99 0.1770756 1 1 92.19 0.04 0.00
1460.00 0.1770665 1 1 92.19 0.04 0.00
0.00 0.1770044 1 1 92.19 0.04 0.00
!end
```

Note: "1" is the normal status for NMR lock and NMR (stability) flag. The lines #4,#5 and #6 of the header give the data entered by the operator. The result is a map from -1460 to +1460mm with an uniform 20mm step size. This input is the standard one for the needs of ARC.

2.5 Fast Raster ^{9 10}

The beam is rastered on target with an amplitude of several millimeters to prevent overheating. The raster is a pair of horizontal (X) and vertical (Y) air-core dipoles located 23 m upstream of the target. The raster has been used in two different modes, sinusoidal and amplitude modulated. In the sinusoidal pattern both the X and Y magnet pairs are driven with pure sine waves with 90° relative phase, and frequencies which do not produce a closed Lissajous pattern. In the amplitude modulated (or square root of time) mode both the X and Y magnets are driven at 18 kHz with a 90° phase between X and Y producing a circular pattern. The radius of this pattern is changed by amplitude modulation at 1 kHz. The radius modulation is controlled by a function generator whose function creates a uniform distribution of the area swept out by the beam motion. It is not possible to switch on the fly between the two modes of operation as hardware changes are required.

One can view the status of the raster in the EPICS overview screen called “General Accelerator Parameters” where the set-point for the radius amplitude and the readback of the peak-current in the raster are displayed.

Control of the raster is done by first asking the MCC operators to set up the raster for a particular radius, typically 2.5 mm. The control software assumes a field-free region between the raster and the target, so it is only approximately correct because there are four quadrupoles in this region. It is important to check the raster spot size and make adjustments if necessary. The main adjustment is made by asking MCC to change the radius. Relatively small independent adjustments to the gains on the X and the Y raster coils are available in the middle room of the hall A counting room using the “PGA Controller” knobs. Near these knobs is also located an oscilloscope X-Y trace of the current in the raster. A fast shutdown (FSD) shuts the beam down within 0.1 msec if the raster fails, thus affording some protection of the target.

NOTE: If you are unsure of the status of the raster, measure the spot size with very low current ($\leq 2\mu A$) or with the target out of the beam. An unfortunately common and potentially fatal error is to check the beam spot size with high current on target; by the time you check it, the target might already be destroyed. The rastered beam spot on target can be checked with plots in ESPACE or by using the stand alone code called “spot”. Spot is probably already running somewhere; it runs on the Linux or Sun computers in the counting room; if it’s not running, type “spot”. When a new CODA run is started, spot automatically clears its histograms and displays in a window the X-Y beam position monitor coordinates from the first few thousand events from the start of the run. For more details on usage, type “spot -h” (help).

⁹ CVS revision Id: raster.tex,v 1.3 2003/06/06 15:19:03 gen Exp

¹⁰ Authors: ?? <mailto:??@jlab.org>

2.6 Target Chamber ^{11 12}

The Hall A target chamber is a large evacuated multistaged can that contains the target struck by the CEBAF electron beam. The chamber was designed to isolate the beam line vacuum from each HRS so that each HRS could rotate around the target without vacuum coupling and without jeopardizing certain desired kinematic and acceptance specifications of both high resolution spectrometers needed for approved experiments. It was also designed to simultaneously contain a liquid or gas target and an array of water cooled thin metallic foils, both remotely controlled and also be adaptable for the waterfall target. The desired kinematic specifications that were considered included momentum and energy resolution in both arms, angular range of spectrometers, angular acceptance, and luminosity. The chamber vacuum is isolated from the HRS by using thin aluminum foils.

The target chamber is designed so that each spectrometer will have continuous coverage in the standard tune from $\theta_{min}=12.54^\circ$ to $\theta_{max}=165^\circ$.

The target chamber is supported by a 24 *in* diameter pivot post secured in concrete, rising about 93.6 *in* above the Hall A cement floor. The Hall A target chamber consists of an aluminum middle ring, a stainless steel base ring, each with a 41.0 *in* inner diameter, and a stainless steel cylindrical top hat with 40 *in* inner diameter to enclose the cryotarget and secure the cryogenic connections.

The aluminum ring with an outer diameter of 45.0 *in* and wall thickness 2.0 *in* is necessary for a sturdy support structure and to permit machining of the outside surface to accommodate the flanges for fixed and sliding seals mounted on opposite sides of the ring that vacuum connect the chamber to each HRS. The height of the aluminum ring shown is 36.0 *in*, which is designed to accommodate the mounting flanges. The stainless steel base ring is 11.50 *in* in height with one pump-out 6 *in* diameter port and with seven 4 *in* viewing and electrical feed-through ports. The base ring will also contain support mechanisms for the solid target ladder assembly, a rotisserie for collimating slits, radiators, and magnetic fingers for removing the solid target vacuum-lock can. The total height of the top ring, middle ring, and base ring is 93.81 *in*. This length is partly determined by our desire to include with the cryogenic extended target a solid target vertical ladder secured in an inverted hat through a hole in the base of the chamber.

The base ring includes an end plate through which the inverted hat will be adapted to fit into the large vertical pipe serving as the pivot post for the Hall A spectrometers.

The stainless steel cylindrical top hat has 40.0 *in* inner diameter, and is 0.375 *in* thick and 46.31 *in* high, which is necessary to permit the cryotarget to be withdrawn and to make space available to expose the solid targets to the electron beam.

The 200 μ A electron beam, presumably focussed to a 0.1 *mm* \times 0.1 *mm* spot and rastered ± 5 *mm* horizontally or vertically on the target, enters through a oval hole in the middle ring which is 2.06 *in* wide and exits through a 1.81 *in* hole connected to the exit pipe.

¹¹ CVS revision Id: tgtcham.tex,v 1.3 2003/06/06 15:19:03 gen Exp

¹² Authors: ?? <mailto:??@jlab.org>

Target Chamber - Spectrometer Coupling

The aluminum middle ring will support a flange on each side for each high resolution spectrometer. Four flanges will be available: Two flanges will contain a 6 *in* window opening which will be covered with a thin foil (e.g., 10 mil aluminum) . These two flanges will be used for experiments utilizing extended targets that do not require optimum momentum resolution. The other two flanges will have two fixed ports (with a 8 *in* \times 6 *in* opening) which will be mainly used for calibration of the spectrometers . Fixed ports are centered at 16.11 ° and 45 ° for one flange and at 16.11 ° and 90 ° for the second flange.

For a point beam on target a vertical opening in the walls of the chamber of height 57.15 cm \times 0.065 \times 2 = 7.43 cm is required so that the scattered beam is within full acceptance of the spectrometer. If the beam is rastered on target ± 0.5 cm in the vertical direction, then the opening in the outer side of the chamber must be at least 8.5 cm for full acceptance.

From consideration of the angular range of the spectrometers in the standard tune, the scattered beam acceptance envelope, the effects of an extended gas target on acceptance, and the effects of a rastered beam ± 5 mm on acceptance, the target chamber requires a window of at least 8.5 cm high in the aluminum ring extending from 6.33 ° (2.48 *in*) from the beam exit point to 8.83 ° (3.47 *in*) from the beam entrance point on one side and a similar window on the other side of the beam. For future considerations (e.g., using a third arm or sliding seal) the width of the window on the middle ring was actually constructed to be 17.78 cm (7 *in*).

Stress Analysis of the Middle Ring

Since the middle ring has an extensive cut across the midplane on both sides as well as entrance and exit holes and loaded with about 25,000 lbs, calculations of the stresses and deformation of the midplane support area of the middle ring and deflection of the window opening were made using the finite element analysis code ANSYS . The work was conducted by a graduate student in the Department of Civil Engineering at the University of Virginia and a REU student. A scaled down model of the middle ring was constructed and then tested by applying forces to it using the Materials Testing Service of the Department of Transportation at the University. ANSYS was first checked by comparing calculations of the test model deflections to the actual data. Agreement was within $\pm 10\%$. Results of ANSYS for the target chamber showed that the maximum deflection of the opening of the window in the middle ring varied from 0.007 *in* to 0.015 *in* depending on how the middle ring was loaded. This was decided to be a safe limit. In the final design, several movable 7 *in* long, 2 *in* diameter aluminum support rods are placed in the window for added support. In addition, flanges defining the ports and coupling to the spectrometers can be added, giving additional support to the middle ring. Compressional stresses, calculated using ANSYS assuming the middle ring was attached to the top hat and loaded with 25,000 lbs, were less than 3000 psi almost everywhere. However, stresses over small areas rose to levels 6000 psi near the entrance and exit

holes. These calculations indicated that we did not exceed the safety limit of 15,000 psi for aluminum. A simple model calculation shown in Appendix A gives the result 1434 psi, which represents some average value over the midplane contact area.

Vacuum Pumping System

The vacuum in the target chamber is maintained by an Alcatel (880 l/s) turbomolecular vacuum pump. The pump is connected to a 6 *in* port in the stainless steel ring between $130^\circ \leq \theta_p \leq 180^\circ$. The vacuum pump is fastened to a horizontal pipe connected to the chamber. The vacuum pressure in the chamber is about 10^{-5} mm. An additional Alcatel pump connected to an 8 *in* port should be added to obtain lower vacuum. Both pumps may be isolated from the target chamber using gate valves which are remotely operated from the vacuum control rack and interlocked to the FSD system.

A 2 *in* all metal gate valve is located between the entrance flange to the chamber and the beam profile monitor. An additional gate valve is located 2 m downstream of the target chamber to isolate the chamber from the exit beam pipe.

2.7 Bremsstrahlung Radiator ^{13 14}

2.7.1 Overview

The Bremsstrahlung radiator is the last element in the Hall A beam line before the scattering chamber, and is about 72.6 cm from the center of the physics targets. Its design is based on the Hall C radiator system built by David Meekins, and documented in the Hall C operations manual.

The central component of the system is a U-shaped, oxygen-free copper target ladder, with six positions for differing thicknesses of oxygen-free Cu foils. The ladder is designed so that it never intersects the beam. The 3.175-cm wide gap in the ladder is spanned only by the target foils, which are 6.35 cm wide, 3.175 cm high, and 3.332 cm apart (center to center). A stepper motor moves the target ladder with foils up and down, into and out of the beam. Hard stops prevent motion of the ladder beyond the limit switches. Water cooling of the radiator ladder cools the foils, preventing damage from overheating by the beam.

The interaction of the beam with the foils produces background radiation in the Hall. At 3 GeV, ion chamber trip levels do not need to be adjusted, and increases in detector background rates are minimal; further tests are planned for 0.8 GeV. No local shielding is installed, as calculations indicate that this will not significantly affect dose at the site boundary. Any installation and/or subsequent modifications must be coordinated with RadCon.

2.7.2 Safety Issues

The only safety issue concerning the Bremsstrahlung radiator is that of induced radioactivity in the Cu targets and in the water used for cooling the targets. The water cooling system is a closed loop, using a portable welding-torch water cooler, located under the beam line just upstream of the target. The cooler is kept in a tray which is intended to provide secondary containment in case of a leak. The cooling system must not be breached or drained without concurrence from the RCG. Accidental breach or spill constitutes a radiation contamination hazard. A spill control kit, capable of containing a system leak or spill, is staged by the door to the hall. In the event of a spill notify the RCG.

2.7.3 Operations

Although the radiator foils are water cooled, a high current electron beam may melt the foils. Beam currents with the radiator will be limited to 30 micro-amperes. Including a safety factor, the raster radii given in Table 1 will limit the temperature rise to 100 °C.

¹³ CVS revision Id: radiator.tex,v 1.3 2003/06/06 15:19:03 gen Exp

¹⁴ Authors: A.Saha <mailto:saha@jlab.org>

Table 2.4: Raster radius as a function of beam current.

Current (μA)	Minimum raster radius (mm)
10	(not needed)
15	0.2
20	0.7
25	1.3
30	2.1

Table 2.5: Encoder voltage calibration. See text.

Position	Voltage ratio	V_{encoder} for $V_{\text{supply}} = 5 \text{ V}$
out limit	0.030	0.15
foil 1	0.102	0.511
foil 2	0.269	1.346
foil 3	0.436	2.179
foil 4	0.603	3.013
foil 5	0.769	3.847
foil 6	0.936	4.681
in limit	0.966	4.831

The only operational control consists of moving the ladder in and out. Radiator position is determined by the ratio of the readback voltage from a linear encoder to the voltage applied to it. Table 2 gives the radiator position as a function of this ratio. The foil thicknesses are set so that the thickness, in percent of a radiation length, equals the foil number, except that no foils are mounted in position 1.

Software controls of the ladder position are under development; radiator position is changed by calling MCC and requesting that the radiator be set to some foil position, or to the out limit. The position may be changed with beam on. A manual-control backup system also exists.

Both software and manual backup systems control an Oregon Micro Systems MH10DX step motor driver, which drives a Slo-Syn M063-LS09 stepper motor. The MH10 driver, power supplies, and other control circuitry, are in a custom-built box located in the hall in rack 1H75B10. The linear encoder voltage ADC is in slot 5 of the CAMAC crate in rack 1H75B02; radiator inputs use channels 15 and 16, and are connected through a patch panel to block 30 in rack 1H75B08.

When the radiator is not being used, the system should be set to the out-limit

position, so that it is clear of the beam. Power to the control box in the hall may be turned off with a front-panel switch if the radiator will not be used for a long time - and should be turned off if work is to be done on the radiator. This deactivates the limit switches and the linear encoder, but does not affect positioning. Additional hard stops should be installed as a safety measure. The Hall A technical staff checklist, done as part of preparations for closing the Hall for beam, includes checking the radiator position, the status of the control box, and the installation of hard stops.

2.7.4 Special Instructions

Care must be taken in case any removal or disassembly of the radiator system is needed. Disconnecting the stepper motor from the motor driver while power is on can damage the motor, motor driver, and VME44 board.

The Cu targets will certainly be activated in the course of an experiment. Therefore, only remove the Cu target, the target ladder, and/or the whole radiator system in the presence of a Radcon officer.

Ron Gilman should be informed in case of any problems with the radiator. Except for normal operations of the radiator, any work on the system hardware requires that RadCon has concurred in the work and either Ron Gilman or David Meekins is present.

2.8 Møller Polarimeter^{15 16}

2.8.1 Purpose and Layout

The Hall A beam line is equipped with a Møller polarimeter whose purpose is to measure the polarization of the electron beam delivered to the hall.

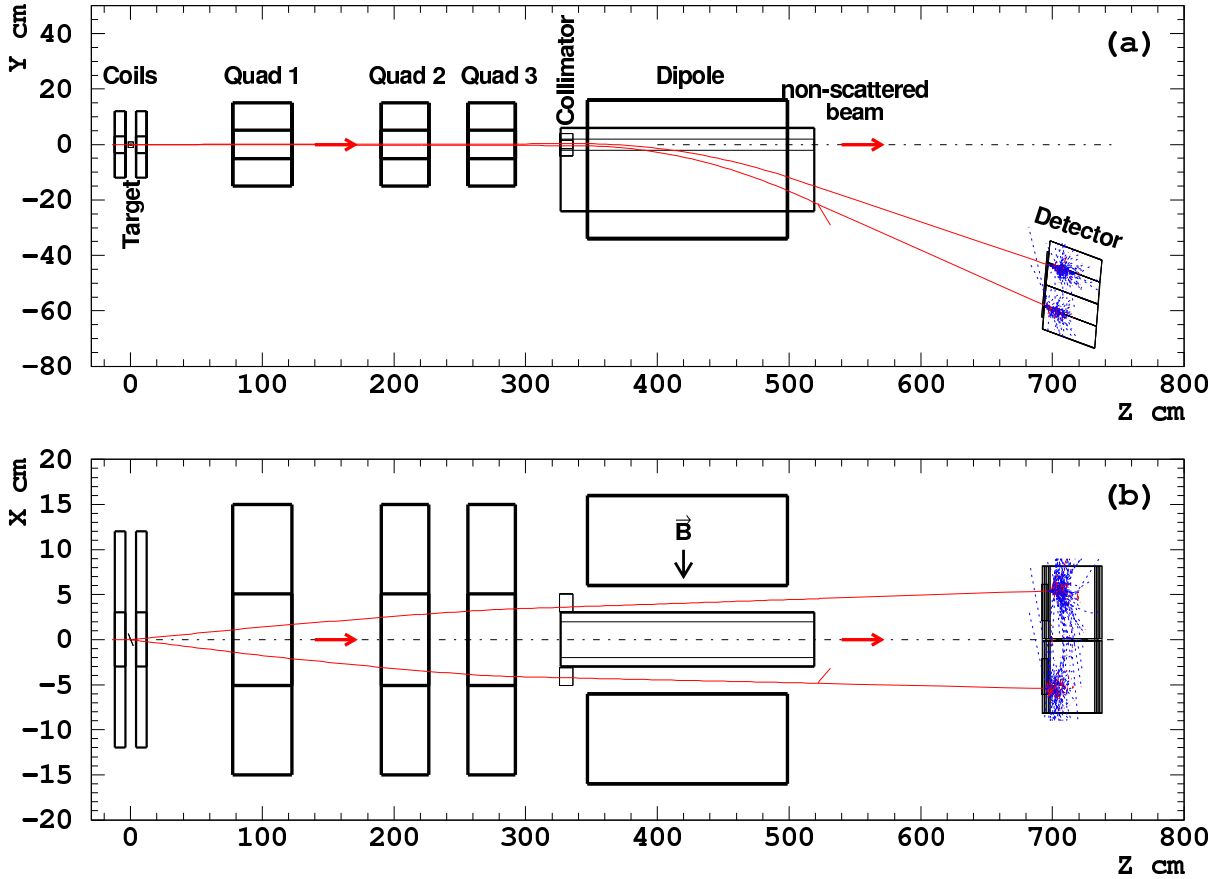


Figure 2.6: Layout of Møller polarimeter. The origin of the coordinate frame is at the center of the polarimeter target, which is 17.5 m upstream of the Hall A target.

The Møller polarimeter consists of (see Fig. 2.6):

- a magnetized ferromagnetic foil used as a polarized electron target, placed 17.5 m upstream of the central pivot point of the Hall A High Resolution Spectrometers;
- a spectrometer consisting of three quadrupole magnets and a dipole magnet, used to deflect the electrons scattered in a certain kinematic range towards the Møller detector;

¹⁵ CVS revision Id: moller.tex,v 1.6 2003/06/06 21:41:39 gen Exp

¹⁶ Authors: E.Chudakov <mailto:gen@jlab.org>

- a detector and its associated shielding house;
- a stand alone data acquisition system;
- off-line analysis software which helps to extract the beam polarization from the data immediately after the data are taken.

The beam polarization is measured by measuring the difference in the counting rates for two beam helicity samples.

There are also external resources of information¹⁷.

2.8.2 Principles of Operation

The cross-section of the Møller scattering $e^- + e^- \rightarrow e^- + e^-$ depends on the beam and target polarizations \mathcal{P}^{beam} and \mathcal{P}^{target} as:

$$\sigma \propto (1 + \sum_{i=X,Y,Z} (A_{ii} \cdot \mathcal{P}_i^{targ} \cdot \mathcal{P}_i^{beam})), \quad (2.1)$$

where $i = X, Y, Z$ defines the projections of the polarizations. The analyzing power A depends on the scattering angle in the CM frame θ_{CM} . Assuming that the beam direction is along the Z-axis and that the scattering happens in the ZX plane:

$$A_{ZZ} = -\frac{\sin^2 \theta_{CM} \cdot (7 + \cos^2 \theta_{CM})}{(3 + \cos^2 \theta_{CM})^2}, A_{XX} = -\frac{\sin^4 \theta_{CM}}{(3 + \cos^2 \theta_{CM})^2}, A_{YY} = -A_{XX} \quad (2.2)$$

The analyzing power does not depend on the beam energy. At $\theta_{CM} = 90^\circ$ the analyzing power has its maximum $A_{ZZ}^{max} = 7/9$. A transverse polarization also leads to an asymmetry, though the analyzing power is lower: $A_{XX}^{max} = A_{ZZ}^{max}/7$. The main purpose of the polarimeter is to measure the longitudinal component of the beam polarization.

The Møller polarimeter of Hall A detects pairs of scattered electrons in a range of $75^\circ < \theta_{CM} < 105^\circ$. The average analyzing power is about $\langle A_{ZZ} \rangle = 0.76$.

The target consists of a thin magnetically saturated ferromagnetic foil. In such a material about 2 electrons per atom can be polarized. An average electron polarization of about 8% can be obtained. In Hall A Møller polarimeter the foil is magnetized along its plane and can be tilted at angles $20 - 160^\circ$ to the beam. The effective target polarization is $\mathcal{P}^{target} = \mathcal{P}^{foil} \cdot \cos \theta^{target}$.

The secondary electron pairs pass through a magnetic spectrometer which selects particles in a certain kinematic region. Two electrons are detected with a two-arm detector and the coincidence counting rate of the two arms is measured.

The beam longitudinal polarization is measured as:

$$\mathcal{P}_Z^{beam} = \frac{N_+ - N_-}{N_+ + N_-} \cdot \frac{1}{\mathcal{P}^{foil} \cdot \cos \theta^{target} \cdot \langle A_{ZZ} \rangle}, \quad (2.3)$$

¹⁷ (Home page: <http://www.jlab.org/~moller/>)

where N_+ and N_- are the measured counting rates with two opposite mutual orientation of the beam and target polarizations, while $\langle A_{ZZ} \rangle$ is obtained using Monte-Carlo calculation of the Møller spectrometer acceptance, \mathcal{P}^{foil} is derived from special magnetization measurements of the foil samples and θ^{target} is measured using a scale, engraved on the target holder and seen with a TV camera, and also using the counting rates measured at different target angles.

The target is rotated in the horizontal plane. The beam polarization may have a horizontal transverse component, which would interact with the horizontal transverse component of the target polarization. The way to cancel the influence of the transverse component is to take an average of the asymmetries measured at 2 complimentary target angles, say 25 and 155°.

2.8.3 Description of Components

MEDM Control

Several components of the polarimeter, namely the target position and the current in the magnets can be checked using the regular MEDM program of Machine Control Center (MCC). The appropriate window 2.7 can be called from the Hall A MEDM menus. Only the MCC can change the values in this window.

Polarized Electron Target

The Møller Polarized Electron Target is placed on the beamline 17.5 m upstream of the main Hall A physics target. The photograph on Fig. 2.8 shows the target chamber, the beam pipe, Helmholtz coils and other elements.

Two target slots exist, called “bottom” and “top”. For the Møller target at the moment a supermendur foil 12 μm thick is used, positioned in the “bottom” slot. The target block can be moved vertically from the center, which contains the hole for the beam, to either “bottom” or “top” position. The foil can be tilted to the beam at an angle required, in a range from 20° to 160°.

Both vertical movement of the target and its rotation is controlled by the Machine Control Center (MCC) operators. The vertical movement is controlled by 3 buttons on the Møller MEDM display, named “center”, “bottom” and “top”. Rotation is controlled by typing an angle, measured in certain units, in a “rotary” window and pressing RETURN. The size of the unit is defined by the end switches which stop the target rotation at low and high end points. The distance between these 2 switches is about 140°, and this distance is divided into 80 units. Therefore one unit is about 1.75°. In order to turn the target to 90° one should set a value of about 38 units. The default rotary position is at 0 units and the target cannot be moved vertically being at a different position.

Before the target is moved vertically the target movement should be “masked” by the MCC operators, since the vertical movement may bring thick construction elements into the beam area and therefore is connected to the Fast Shutdown (FSD). The target rotation is safer and can be performed without “masking” the target movement and

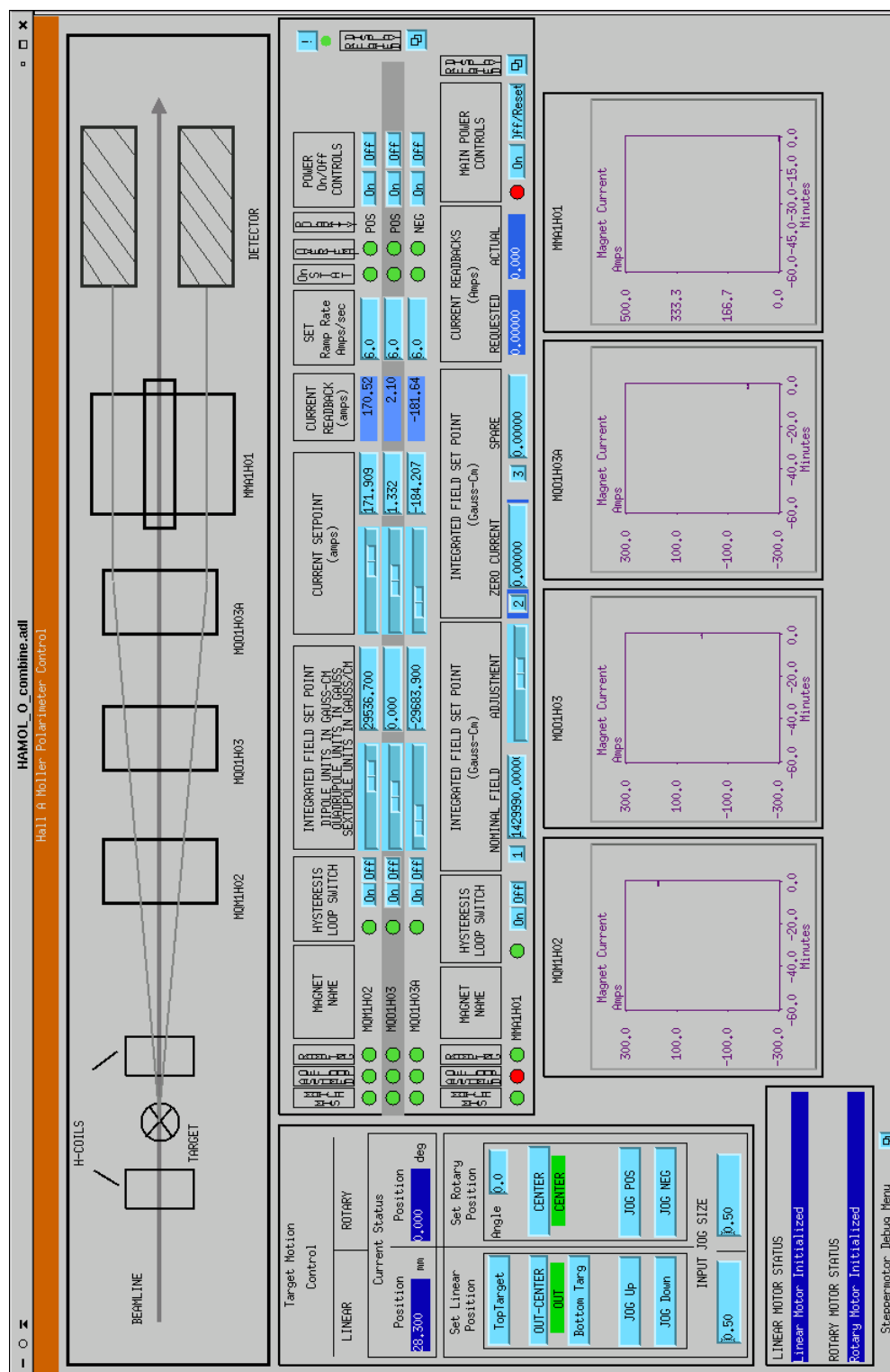


Figure 2.7: The Møller MEDM MCC control.

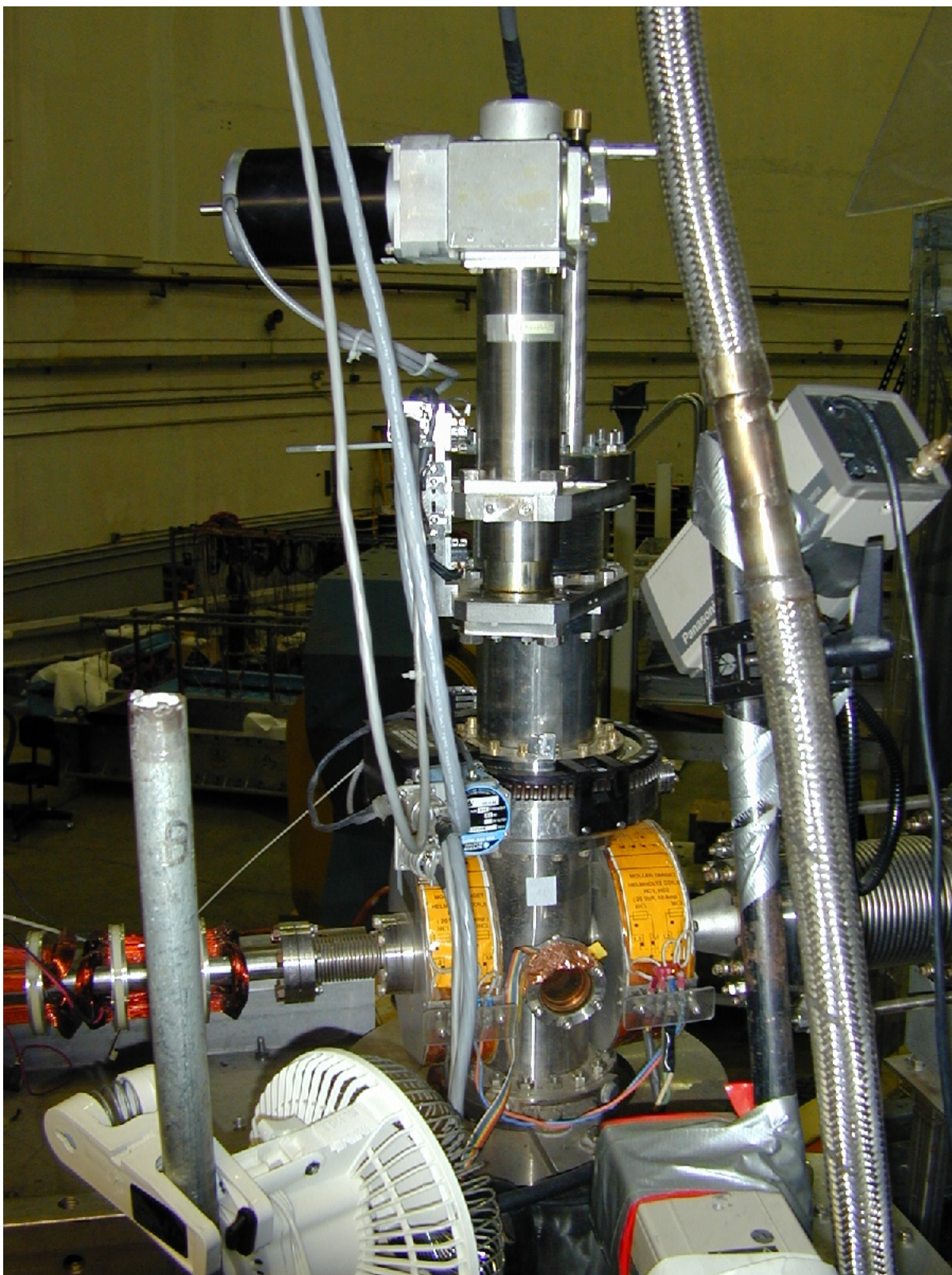


Figure 2.8: The Møller target.

is normally performed without turning off the beam. A potentially dangerous target rotation to angles lower than 15° is prevented mechanically.

The target motion is supervised using 2 TV cameras, displayed in Hall A counting house. One camera is looking from the side. A glass window in the target vacuum box allows one to see the beam area in the place where a target can be moved in. The central position (empty) of the target block is seen as an empty round hole. A target moved in is clearly visible. The second camera looks from the top at the target holder. A scale (Fig. 2.9) engraved on the holder shows its angle in degrees. This scale gives correct

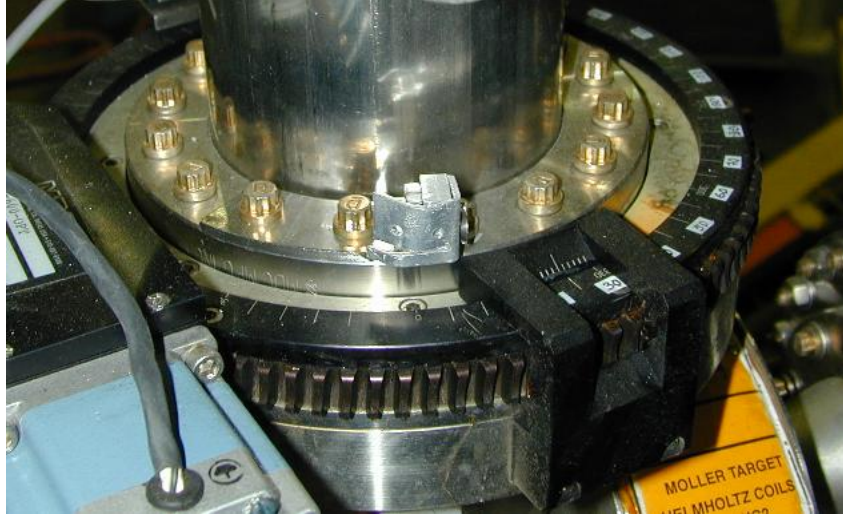


Figure 2.9: The Møller target rotary dial.

relative angles of the target. The absolute angle of the target to the beam is measured using the event rates, measured at a given target angle and at about 90° . At the moment the scale has a shift, that: $\theta^{target} \approx \theta^{scale} - 2.5^\circ$.

The target is magnetically saturated using 2 external Helmholtz coils, providing a field of about 240 Gs along the beam axis at the target center. The coils are turned on by the Møller CODA task, during the data taking. Its polarity is reversed for each new run of data taking (one run typically takes 2-3 min).

The beam of a few μA may heat up the target locally by 20-40K, which may change slightly the target polarization. Therefore the beam current is limited to about $2\mu\text{A}$ ¹⁸ because of heating, while the dead time problems actually limit the current to about $0.5\mu\text{A}$.

The temperature of the target holder is measured using cernox resistors.

The target magnetization has been measured before the installation¹⁹.

¹⁸ A system for cooling the target with liquid nitrogen has been built. However, it has not been used and there are no plans to use it.

¹⁹ The magnetization can be also measured in situ, by changing the field in the Helmholtz coils and measuring the voltage at pick-up coils, wound around the target foils, although this method is less accurate than the lab method and has not been used.



Figure 2.10: The Møller spectrometer. The target is located at the right side of the photograph, the blue dipole magnet is close to the center.

Spectrometer Description

The Møller polarimeter spectrometer consists of three quadrupole magnets and one dipole magnet (see Fig. 2.6 and also Fig. 2.7):

- quadrupole **MQM1H02** (on the yoke labeled *PATSY*);
- quadrupole **MQO1H03** (on the yoke labeled *TESSA*);
- quadrupole **MQO1H03A** (on the yoke labeled *FELICIA*)
- dipole **MMA1H01** (on the yoke marked as *University of Kentucky*).

The photograph on Fig. 2.10 shows the side view of the spectrometer.

These magnetic elements are controlled by MCC operators.

The spectrometer accepts electrons scattered close to the horizontal plane (see Fig. 2.6). The acceptance in the azimuthal angle is limited by a collimator in front of the dipole magnet, while the detector vertical size and the magnetic field in the dipole magnet limit the acceptance in the scattering angle θ_{CM} .

The electrons have to pass through the beam pipe in the region of the quads, through the collimator in front of the dipole magnet, with a slit of 0.3-4 cm high, through two

vertical slits in the dipole, about 2 cm wide, positioned at ± 4 cm from the beam. These slits are ended with vacuum tight windows at the end of the dipole. The dipole deflects the scattered electrons down, towards the detector. The detector, consisting of 2 arms - 2 vertical columns - is positioned such that electrons, scattered at $\theta_{CM} = 90^\circ$ pass close to its center. This acceptance is about $76 < \theta_{CM} < 104^\circ$. At beam energies below 1 GeV the vertical slits in the dipole limit the acceptance to about $83 < \theta_{CM} < 97^\circ$.

For a given beam energy there is an optimal setting of the currents in these 4 magnets (see section 2.8.4). At energies higher than 2.5 GeV it is possible to optimize the beam line for both regular running and for Møller measurements. Typically, the dipole magnet should be turned on only for the Møller measurements.

Detector

The Møller polarimeter detector is located in the shielding box downstream of the dipole and consists of two identical modules placed symmetrically about a vertical plane containing the beam axis, thus enabling coincidence measurements. Each part of the detector includes:

- An aperture detector consisting of a $28 \times 4 \text{ cm} \times 1 \text{ cm}$ scintillator with Plexiglas light guide and a Hamamatsu R1307 (3 inch) photomultiplier tube.
- A “spaghetti” lead - scintillating fiber calorimeter²⁰, consisting of 2 blocks $9 \times 15 \times 30 \text{ cm}^3$, each separated into 2 channels equipped with Photonis XP2282B (2 inch) photomultiplier tubes. Thus, The vertical aperture is segmented into 4 calorimeter channels.

The HV crate is located in the Hall A rack 15 and is connected to a portserver *hatsv5*, port 11. HV for the lead glass detectors is tuned in order to align the Møller peak position at a ADC channel 300 for each module, which means that the gain of the the bottom modules is about 50% higher than the gain of the top modules.

Electronics

The electronics, used for Møller polarimetry, is located in several crates in the Hall:

1. VME, board computer *halladaq14* - for Helmholtz coils control;
2. VME, board computer *hallavme5* - for DAQ;
3. CAMAC - for the trigger and data handling;
4. NIM - for the trigger and data handling;
5. LeCroy 1450 - HV crate, slot 4.

The photograph on Fig. 2.11 shows the crates 2-4. One can connect to the CPU boards and the HV crate via a portserver:

1. *halladaq14* - *hatsv5* port 3;

²⁰ before summer 2002 a lead glass calorimeter consisting of 4 $8 \times 8 \times 30 \text{ cm}^3$ was used. It lost a big fraction of the amplitude due to the radiation damage and deterioration of the optical contact.

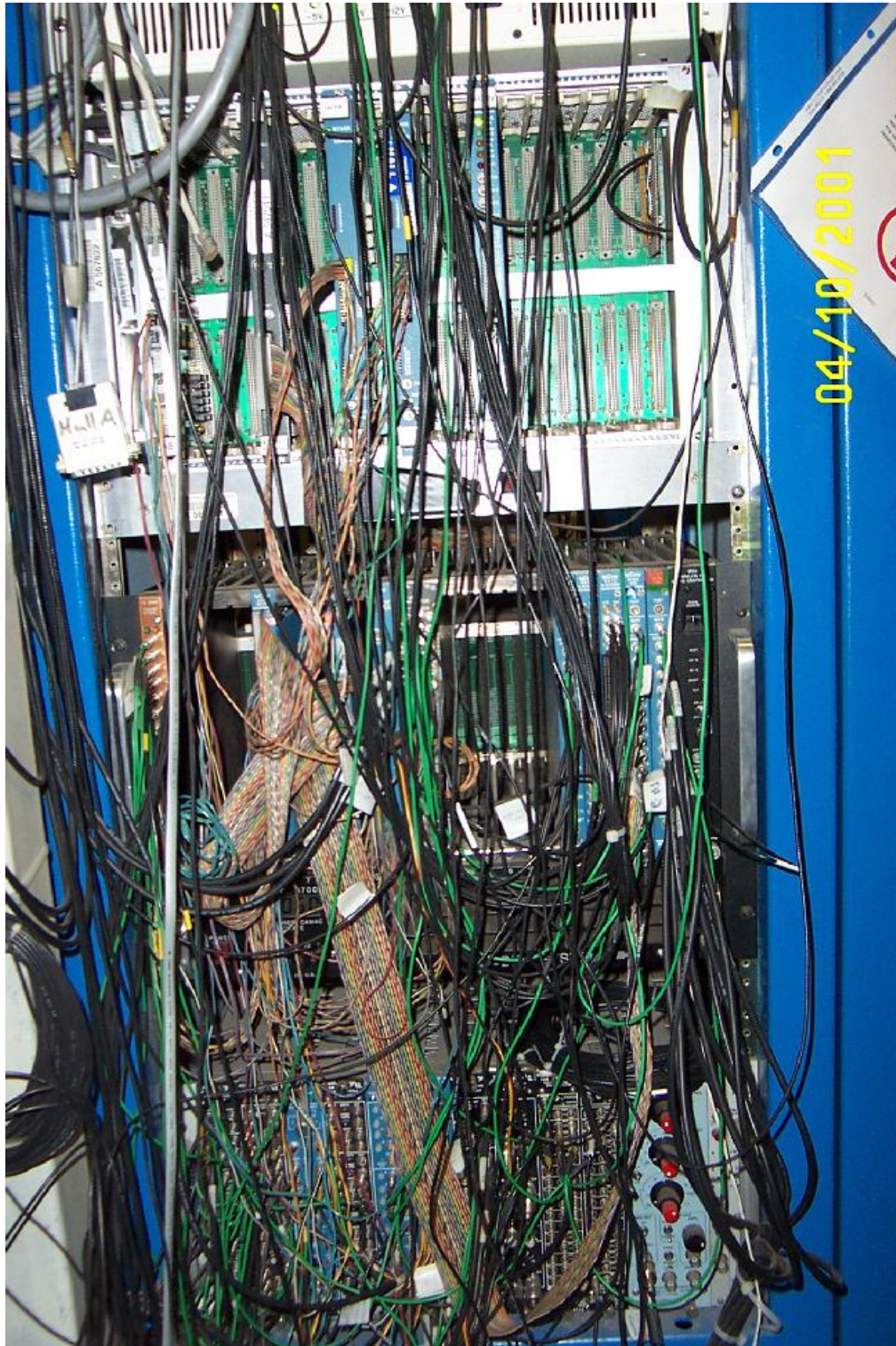


Figure 2.11: The Møller electronics, located in the Hall, at the right side of the beam line. The top crate is the VME DAQ crate, the middle one is the CAMAC crate and the bottom one is the NIM crate. The first VME crate, used to control the Helmholtz coils, is above these three.

2. `hallavme5` - `hatsv5` port 4;
5. LeCroy 1450 - `hatsv5` port 11.

The Møller target positions are connected to the Fast ShutDown (FSD) system of the accelerator. The photograph on Fig. 2.12 shows the crate which controls the signals.



Figure 2.12: The Møller target motion may cause the Fast ShutDown (FSD) of the accelerator. The LEDs in the top right corner show the appropriate signals from the target. The top LED lit indicates no FSD signal.

DAQ

The DAQ²¹ is based on CODA [4] and runs at `adaql2`, connecting to `hallavme5`. The database server for CODA is located on `adaqs2`.

²¹(More details in: http://www.jlab.org/~moller/guide1_linux.html)

Slow Control

The Helmholtz coils are controlled via a script starting automatically at the beginning of each CODA run. The polarity of the current in the coils is reversed at every new run.

The HV, the electronics settings and the collimator position are controlled from a Java program, equipped with a GUI.

Start the slow control task:

- Login to `adaql1` as `moller`;
- `adaql1> cd Java/msetting/`
- `adaql1> ./mpc` - start the slow control task.

It may take about a minute to start all the components and read out the proper data from the electronic crates. The slow control console is presented on Fig. 2.13. The

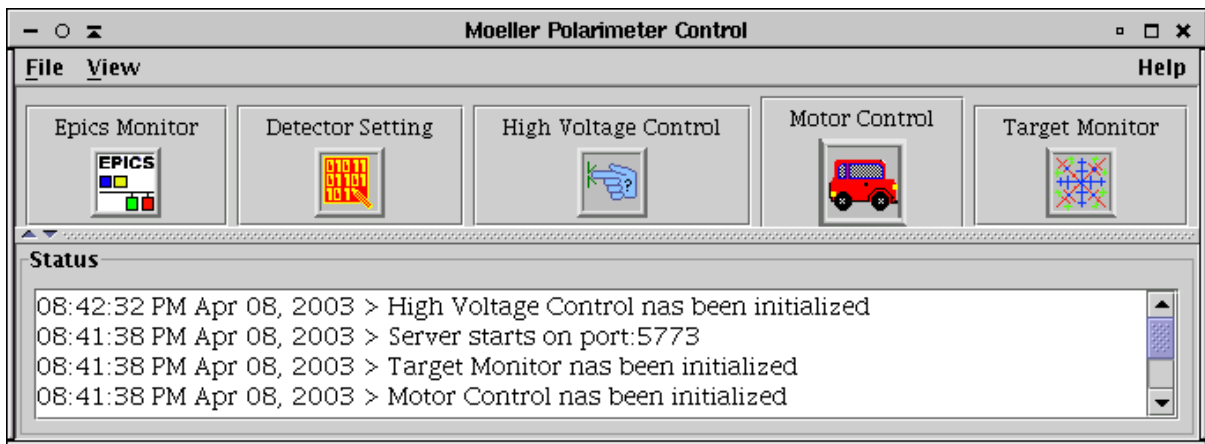


Figure 2.13: The slow control console (Java).

components are:

- **EPICS Monitor**: these EPISC variables are stored for every DAQ run
- **Detector Settings** is used to set up the thresholds, delays etc.
- **High Voltage Control** for the photomultiplier tubes
- **Motor Control** to move the collimator
- **Target Monitor** information on the target position, magnets etc.

High voltage can be changed or turned on/off using the HV console (Fig. 2.14), where the first 8 channels belong to the calorimeter and the other 2 channels belong to the aperture counters. The settings of the CAMAC electronics used to make the trigger and control DAQ are controlled using the **Detector Setting** window (Fig. 2.15):

- **Delay line** - the delays for the calorimeter and counter signals;
- **LedDiscriminator** - discriminator thresholds for the calorimeter and the counters
- **PLU Module** - settings of the logical unit

The collimator width can be changed using **Motor Control** window (Fig. 2.16),

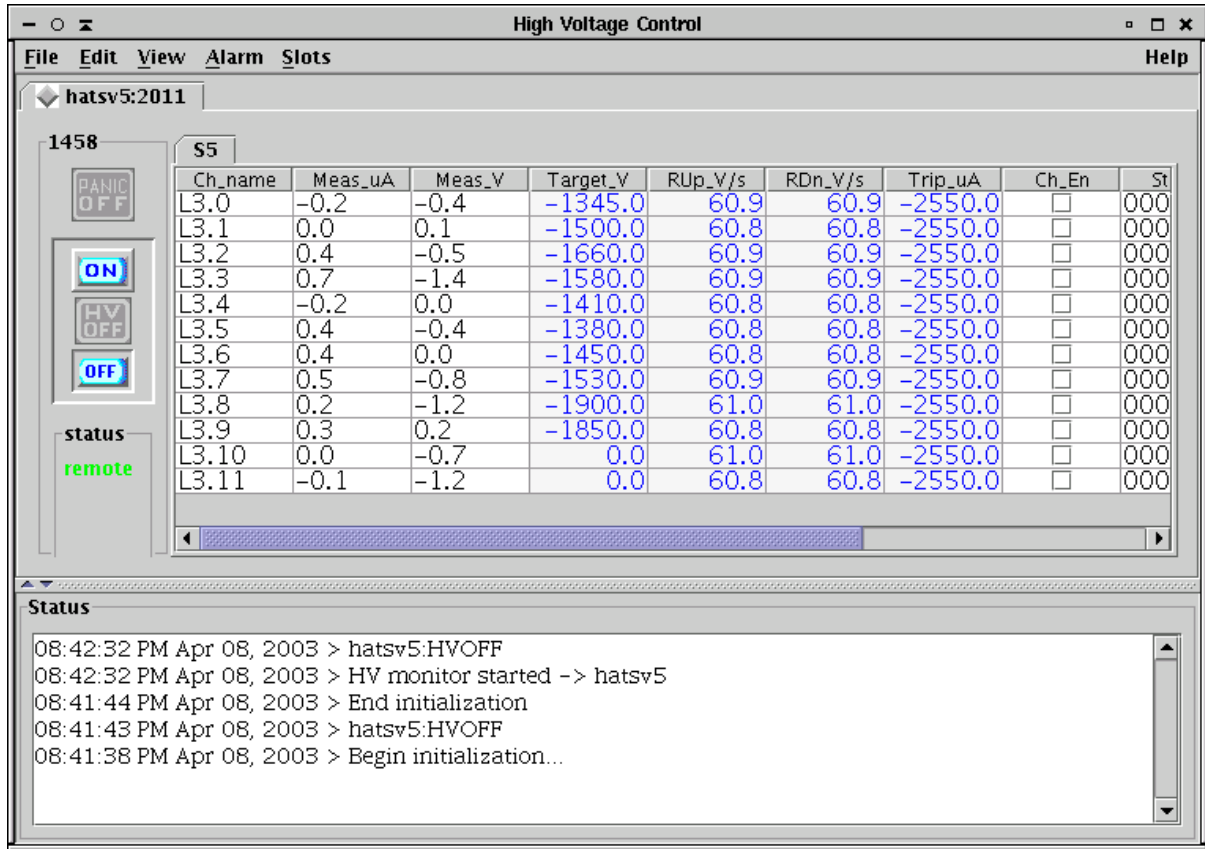


Figure 2.14: HV control console.

2.8.4 Operating Procedure

The procedure includes general steps as follows:

- “Non-invasive” preparations - start the appropriate computer processes, turn on the HV and learn the magnet settings needed;
- “Invasive” preparation: beam tuning with the regular magnet settings, loading the Møller settings, beam tuning, if necessary, installing the Møller target;
- Detector check/tuning;
- Measurements;
- Restoring the regular settings.

The “non-invasive” preparations can be done without disturbing the running program in the Hall. It is reasonable to perform these preparations before starting the “invasive” part.

In more details, the “invasive” procedure looks as follows:

- Remove the main target;

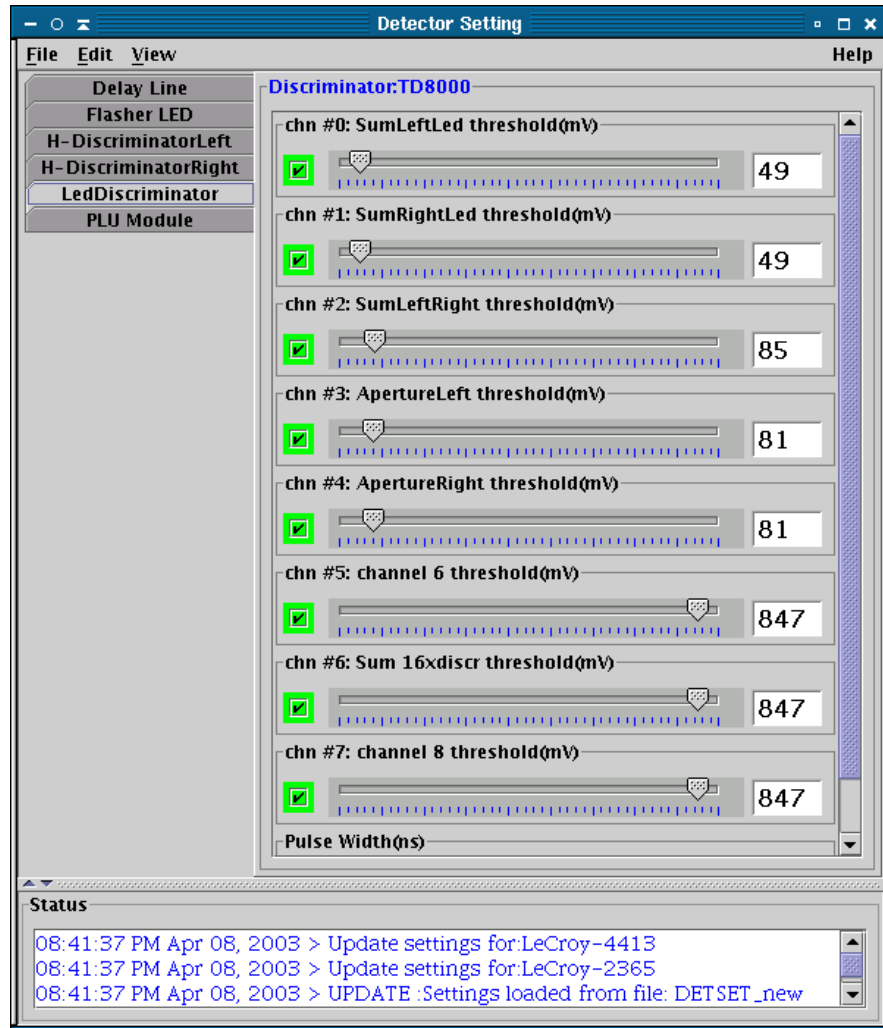


Figure 2.15: Detector setting console.

- Tune the beam position with any convenient beam current;
- Load the Møller settings in the magnets;
- Check the beam position;
- Tune the beam to $\sim 0.3 \mu\text{A}$ for Møller measurements;
- Pull in the Møller target;
- Make measurements at the forward target angle ($\sim 23^\circ$);
- Make 2 short runs at the normal target angle ($\sim 90^\circ$);
- Make measurements at the backward target angle ($\sim 163^\circ$);

Initialization

In order to control the operations several sessions of **moller** account must be opened at computers **adaql1,....** The data analysis and some initial calculations are done using a

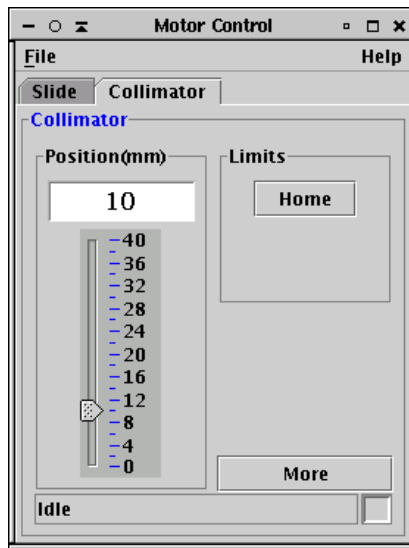


Figure 2.16: Control console for the collimator (and also the slide, which is not relevant here).

PAW [5] session on `adaql1`:

- Login to `adaql1` as `moller`;
- `adaql1> cd paw/analysis`, start PAW (type `paw`), select Workstation type 3.

CODA runs on `adaql2`:

- Login to `adaql2` as `moller`, make two sessions;
- `adaql2> kcode` - clean up the old coda;
- `adaql2> et_start moller &` - start ET if it is not running;
- Reset `hallavme5` and `halladaql4` by pressing two top left green reset buttons in the middle room of the counting house;
- `adaql2> runcontrol` - start CODA;
- Click **Connect** and select the configuration `beam_pol`;
- Click **Download** to download the program into the VME board.

Slow control:

- Login to `adaql1` as `moller`;
- Start the slow control (see section 24);
- Load the regular settings and the appropriate HV.

Initial Beam Tune

Typically, the Møller measurements are taken during the regular Hall A running, when the beam has been tuned for this running. However, the Møller measurements require a different magnetic setting. At least the dipole magnet has to be turned on. This magnet slightly deflects the beam downward. The deflection at the main target could be 2-8 mm, depending on the beam energy. It is, therefore, useful to tune the beam position before the dipole is turned on. It can be done before the magnets are set to the Møller mode. The requirements are:

- On BPM IPM1H01 (in front of the Møller target) $|X| < 0.2$ mm, $|Y| < 0.2$ mm.
- On BPM IPM1H04A/B $|X| < 2$ mm, $|Y| < 2$ mm.

The request should be given to MCC.

The Magnet Settings

In order to find the proper settings for the given beam energy, say 3.25 GeV, type on the PAW session:

PAW> exec sett_magp e0=3.25 nq=3 for 3-quad configuration

PAW> exec sett_magp e0=3.25 nq=2 for 2-quad configuration

The printed values for GL and BdL should be checked with the current values, displayed on the MEDM window 2.8.3. The MCC should be asked to load the Møller settings in the magnets - they have a tool to load the proper settings for the Møller magnets and a few other magnets on the beam line. The set values should be compared with the calculated values²². **The beam must be turned off when the magnets are tuned.**

Final Beam Tune

The beam parameters for Møller measurements are:

- Remove the main target;
- **the beam current ~ 0.3 μ A and < 2 μ A;**
- the beam current should be reduced mainly by closing the “slit” in the injector (not by the laser attenuator), in order to reduce the effect of current leak-through from the other halls.

Target Motion

MCC should be asked to put in one of the targets (typically, the **bottom** (see Fig. 2.7) target is used). The requirements for the target motion are:

- **Vertical motion: beam OFF, target motion MASKED.**
- **Rotation: no constraint, the beam can be ON.**

²²The reasonable accuracy in the magnets settings is about 1-2%

Ask the MCC to resume the same beam and check the Ion Chamber **SLD1H03** reading. It should not exceed 1000. At beam energies above 1.6 GeV it should not exceed 300.

Detector Tuning and Checking

The goal is to check that the detector is working, that the counting rates are normal and that the Møller peaks are located at about ADC channel 300 for all the calorimeter blocks.

A. Data taking with CODA

1. Take a RUN for about 20k events. Let us assume the run number is 9911.

B. Data analysis with PAW

1. **PAW> exec run run=9911**: build an NTUPLE and attach it to the PAW session;
2. **PAW> exec lg_spectra icut=60 run=9911**: look at the ADC distributions. The peaks should be at about ADC channel 300 for all 8 modules. If the peaks are off - try to adjust the HV (do not go beyond 1990V).

C. Check of the background

1. Raise the thresholds to 240 mV of the channels 1 and 2 of the discriminator, using the slow control window (see section 24);
2. Take a run of about 20k events, say run=9915;
3. **PAW> exec lg_spectra icut=60 cut=11 run=9915**: look at the ADC distributions. The peaks should be at about ADC channel 300 for all 8 modules. The histograms 9 and 10 present the sums of the left and right arms. The histogram 11 (sum of both arms) should contain a clean peak at about channel 600;
4. **PAW> exec asyms angl=23.0 run=9915**: polarization analysis should provide a reasonable number. Check the scaler rates per second. The counting rates in each arm should not exceed 600kHz. If they are higher ask the MCC to reduce the beam current.

Polarization Measurement

1. Make a note in the logbook of the target angle on the scale, seen with the TV camera.
2. Take 4 runs of data with the given angle, each run of about 20-30k events (30k at $E_{beam} < 2$ GeV).

3. Ask the MCC to turn the target to 38 units and make a note of the angle on the scale.
4. Take 2 runs of data with the given angle, each run of about 15k events.
5. Ask the MCC to turn the target to 80 units and make a note of the angle on the scale.
6. Take 6 runs of data with the given angle, each run of about 20-30k events (30k at $E_{beam} < 2$ GeV).
7. Analyze the data
 1. `PAW> exec run run=????` and
 2. `PAW> exec asyms run=???? angl=tang`, for each RUN, `tang` is the target angle observed on the scale.
 3. `PAW> call prunpri.f(9000,20000)`, print a table with the results for a given range of runs.

2.8.5 Safety Assessment

Magnets

Particular care must be taken in working in the vicinity of the magnetic elements of the polarimeter as they can have large currents running in them. Only members of the Møller polarimeter group are authorized to work in their immediate vicinity, and only when they are not energized. The quadrupole magnets and the leads for the dipole magnet are protected with Plexiglas shields. As with all elements of the polarimeter which can affect the beamline, the magnets are controlled by MCC. There are four red lights which indicate the status of the magnets. The dipole has two lights which are activated via a magnetic field sensitive switch placed on the coils of the dipole. One light is placed on the floor on beam left, and the other is placed on the raised walkway on beam right. The quadrupoles have similarly placed lights (one on the floor on beam left and one on the walkway), and are lit up when any one of the Møller quads is energized. The status of the quadrupole power supplies is on the checklist for closing up Hall A. Lock and tag training is required of all personnel working in the vicinity of the Møller magnets.

The power supply for the dipole is located in the Beam Switch yard Building (Building 98). The maximum current for the dipole is 450A. The quadrupole power supplies are located in Hall A electronics rack 13, 2 supplies connected in parallel per one quadrupole. The maximum current per one power supply is 60A at about 20V.

Vacuum System

One must be careful in working near the downstream side of the dipole magnet, as there are two 2 by 16 cm, 4 mil thick titanium windows. Only members of the Møller polarimeter group should work in this area.

High Voltage

There are 38 photomultiplier tubes within the detector shielding hut, with a maximum voltage of 3000 V. The detector is serviced by sliding it back on movable rails. The high voltage must be turned off during any detector movement. Only members of the Møller group should move the detector.

Target

To avoid damage to the Møller target, the target should not be in the beam if the beam current is greater than $5 \mu\text{A}$. Only MCC can move the target, but the experimenters are responsible for ensuring that it is properly positioned.

2.8.6 List of Authorized Personnel ^{23 24}

The list of the presently authorized personnel is given in Tab. 2.6. Other individuals must notify and receive permission from the contact person (see Tab. 2.6) before adding their names to the above list.

Name		Dept.	Telephone		e-mail	Comment
			JLab	Pager		
<i>Eugene</i>	<i>Chudakov</i>	JLab	6959	6959	gen@jlab.org	Contact
Alexander	Glamazdin	Kharkov	6378		glamazdi@jlab.org	
Viktor	Gorbenko	Kharkov	6378		gorbenko@jlab.org	
Roman	Pomatsalyuk	Kharkov	6378		romanip@jlab.org	

Table 2.6: Moller Polarimeter: authorized personnel. The primary contact person's name is marked with a slanted font.

²³ CVS revision Id: moller-personnel.tex,v 1.2 2003/06/06 21:12:51 gen Exp

²⁴ Authors: E.Chudakov <mailto:gen@jlab.org>

2.9 Compton Polarimeter ²⁵ ²⁶

²⁵ *CVS revision* Id: compton.tex,v 1.3 2003/06/06 15:19:03 gen Exp

²⁶ Authors: S.Nanda <mailto:nanda@jlab.org>

Chapter 3

Targets

3.1 Overview ¹ ²

The physics program in Hall A utilizes a number of different target systems of varying complexity. There is a set of cryogenic targets which currently operates with hydrogen and deuterium as target materials and will soon support both helium 3 and helium 4.

A variety of solid targets is also provided; BeO, Carbon or Kapton are typical but other self supporting materials are available if need arises.

The combination of cryogenic targets and a few solid targets is the standard configuration. In addition, there is a large program based on polarized helium 3. This is a special installation and hence is not available at the same time as the cryogenic target system.

Finally, a waterfall target was used during the commissioning of the hall and is still available as a resource. This system also requires a special installation.

Each of these systems is discussed in this chapter or in an appendix.

¹ *CVS revision* Id: overview.tex,v 1.3 2003/06/06 17:09:04 gen Exp

²Authors: Dr.No <mailto:????@jlab.org>

3.2 Cryogenic Hydrogen and Deuterium Targets ^{3 4}

The Hall A cryogenic target system consists of two completely instrumented targets, H₂ and D₂. In addition a third target loop is installed in the scattering chamber but this target is not usually connected to a full gas handling system. This third loop is used as a helium target.

The hydrogen and deuterium targets present a number of potential hazards, such as the fire/explosion hazard of the flammable gas as well as the hazards connected with the vacuum vessel and the of handling cryogenic liquids (ODH and high pressure). In this document the hydrogen target will be referred to, but the deuterium target is essentially identical and almost all comments apply to both targets.

3.2.1 Flammable Gas

Hydrogen and deuterium are colorless, odorless gases and hence not easily detected by human senses. Hydrogen air mixtures are flammable over a large range of relative concentrations from 4 % to 75 % H₂ by volume. Detonation can occur with very low energy input, less than $\frac{1}{10}$ that required by mixtures of air and gasoline. At temperatures above -250 °C hydrogen gas is lighter than (STP) air and hence will rise. At atmospheric pressure, the ignition temperature is approximately 1000 °F but air H₂ mixtures at pressures of 0.2 to 0.5 Atm can be ignited at temperatures as low as 650 °F. Hydrogen mixtures burn with a colorless flame [6].

The total volume of liquid hydrogen in the heat exchanger is about 2 *l*. The target cells and their associated plumbing hold an additional 3.4 *l*. Thus the total volume of hydrogen in the target is approximately 5.4 *l*. The volume changes between the liquid state and gas at STP by a factor of about 800. Thus filling the target would require about 4,300 STP *l* of hydrogen. The hydrogen target is connected to a 1,000 Gallon (about 3,800 *l*) recovery tank. The normal running condition for hydrogen is 26 PSIA. So the total amount needed to fill the target and the tank is about 10,900 STP *l*. For deuterium, the target is about 4,300 STP *l*. The normal running condition for deuterium is 22 PSIA. So the total volume needed to fill the tank is about 5,600 *l*. The total to fill both the target and the tank is about 9,900 STP *l*.

The Hall A inventory of hydrogen and deuterium gas is stored outside the Hall A gas shed, adjacent to the counting house. The current inventory is two A size cylinders of hydrogen (\approx 6,800 STP *l* each) and four A size cylinders of deuterium (\approx 5,000 STP *l* each). One bottle of hydrogen and one deuterium bottle will be kept in the Hall in order to fill the targets. These bottles will be placed in a gas rack behind the gas panels.

The basic idea behind safe handling of any flammable or explosive gas is to eliminate oxygen (required for burning) and to prevent exposure to any energy source that could cause ignition. In the Hall A environment, the most likely source of oxygen is of course the atmosphere and the most likely ignition sources are from electrical equipment.

³ CVS revision Id: cryo-c-safety.tex,v 1.3 2003/06/06 17:11:53 gen Exp

⁴Authors: Dr.No <mailto:????@jlab.org>

Electrical Installation

Hall A contains a lot of electrical equipment and almost all of it could serve as an ignition source in the presence of an explosive oxygen and hydrogen mixture. We have made an effort to minimize the dangers from the equipment that is most likely to come into contact with hydrogen gas.

There are a number of electrically powered devices associated with the target gas handling system. All the pressure transducers in the system are approved for use in a hydrogen atmosphere. The solenoid valves on the gas panels are explosion-proof. The AC power for the solenoids is carried by wires which are contained in either hard or flexible conduit. There are also LEDs on the gas panels that provide an indication as to the status of the valve solenoids. These are powered by a 24 V DC supply. The readouts for the pressure transducers are mounted on the gas panels and the AC power for these readout units is in conduit. All the pressure transducers have 4-20 mA outputs.

In addition to the electrical devices in the gas handling system, there are a number of devices inside of or mounted on the scattering chamber.

All the devices which are in the scattering chamber must have their power delivered to them by wires in vacuum. The insulation of these wires should be radiation resistant, so Kapton has been used where available.

The following electrical items are in close proximity to or are actually in the hydrogen system.

Axial Circulation Fan The fans which circulate the hydrogen in the target are AC induction motors and therefore contain no brushes and are practically immune to sparking. The three phase power for these fans is delivered to them by 18 gauge stranded copper wire with Kapton insulation. The maximum current that the fans draw is 5 A for a maximum power consumption of 200 W when pumping liquid hydrogen/deuterium. The current and voltage drawn by the fans is monitored by the control system.

Fan Motor Tachometer The fans have a tachometer which consist of a coil that views the flux change caused by a permanent magnet attached to the motor rotor. The tachometer signals are carried on 22 gauge stranded wire with Kapton insulation. This is a low power signal. The control system monitors the frequency of the fans.

Low Power Heater This is a “hair dryer” style heater (it resembles the heater elements found in hair dryers and heat guns) that is immersed in the hydrogen. The heater is made of 0.0179 in diameter Nichrome wire with a resistance of 1.993 Ω per foot wrapped on a G10 carrier board. The maximum power available to this heater is 80 W. The power for the low power heater is supplied by a Oxford ITC-502 temperature controller. The heater lead wire is 18 gauge Kapton insulated copper stranded wire. The heaters have a DC resistance of 20 Ω and hence will draw a maximum of 2 A. The power supplied to this heater is monitored by the control system.

High Power Heater There are two kapton enclosed incoloy heater foils wrapped on the inside wall of each heat exchanger. The maximum power available to each heater is 500 W. The heater has a DC resistance of 26 Ω and two heaters in parallel are driven by a 150 V, 7 A power supply. The current and voltage supplied to this heater are monitored by the control system and there is a software power maximum enforced on the power setting of this heater. The heater is connected to the outside world by 18 gauge stranded wire with Kapton insulation.

Resistors There are two Allen Bradley and four Cernox resistors immersed in each target loop. These resistors provide temperature measurements of the target fluid. The temperature controllers that read them use a current of less than 30 μ A to excite them (they are excited with a constant voltage which for our resistors is on the order of 30 mV). The Cernox resistors are connected to the outside world with quad strand 36 gauge phosphor bronze wire with Formvar insulation. The Allen Bradley resistors are wired with 30 gauge Kapton insulated copper stranded wire.

Target Lifter There are two AC servo motors which provide the power to lift the target ladder. These motors are powered by three phase 208 V power and are equipped with fail safe brakes (the brakes are **released** by a 24 V DC control voltage) and 50 to 1 gear reducers. On power up, there is a delay relay that insures that the motors are always energized before the brakes are released.

Vacuum Pumps The scattering chamber is evacuated by two Leybold 1000 l/s turbo pumps that are backed by a Leybold 65 cfm mechanical pump. The turbo pumps are powered by 120 V AC power while the backing pump requires three phase 208 V AC power. The motor on the backing pump is explosion proof and approved for use in NEC Class 1, Division 1, Group D (hydrocarbons **but not** hydrogen) environments. An identical mechanical pump is used in the pump and purge system of the gas panels. Both the scattering chamber backing pump and the pump and purge system's mechanical pump exhaust to the vent line.

Vacuum Gauges The chamber vacuum is monitored by an HP cold cathode gauge. This gauge has a maximum operating voltage of 4000 V and a maximum current of 133 μ A. The pressure at the entrance to the roughing pump is measured by a convectron gauge.

Flammable Gas Detectors

There are four flammable gas detectors installed (one on top of the target, one each on top of the hydrogen and deuterium gas panels, one on top of the gas tanks) to provide early detection of hydrogen/deuterium leaks. These detectors are sensitive (and calibrated) over the range from 0 to 50 % Lower Explosive Limit (LEL) of hydrogen. The electrochemical sensors were manufactured by Crowcon Detection Instruments LTD and the readout (four channels) was purchased from CEA Instruments, Inc. (The Gas Master Four System). The readout unit provides two alarm levels per channel. The low level

alarm is tripped at 20 % LEL while 40 % LEL activates the high level alarm. Each channel has a relay output for both low and high level alarm states and there is also a set of common relays for both alarm levels (these common relays respond to the "logical or" of the sensor inputs). The common relays will be connected to the Fast Shut Down System, FSD, which removes the beam from the hall by disabling a grid bias at the injector.

3.2.2 Pressure

The most important aspect of hydrogen safety is to minimize the possibility of explosive mixtures of hydrogen and oxygen occurring. Therefore the gas handling system has been made of stainless steel components (wherever possible) and as many junctions as possible have been welded.

The pressure in the gas handling system is monitored in numerous places. Most importantly, the absolute pressure of the target is viewed by two pressure transducers, one on the fill line, PT127 for H₂ and PT136 for D₂, and one on the return line, PT131 for H₂ and PT140 for D₂. These pressures are also measured by manual gauges. The fill line gauges are PI126 for H₂ and PI135 for D₂. The return line gauges are designated PI130, H₂ and PI139, D₂. The gas tanks are viewed with both pressure transducers (PT133 for hydrogen and PT142 for deuterium) and pressure gauges (PI123 for hydrogen and PI112 for deuterium).

Target Cells

The target cells themselves represent the most likely failure point in the hydrogen system. The outer walls and downstream window of the cells are made of ≈ 0.03 to 0.045 *in* thick 3004 aluminum (Coors beer cans in a former incarnation) (all the final ones are above 0.035 *in*). There are two cells soldered to each cell block, one 15 *cm* long and one 4 *cm* long. Both cells have an outer diameter of approximately 2.5 inches. The upstream windows of the cells are made from 0.0028 *in* thick 5052 aluminum. These windows are soldered to 1.75 *in* diameter (0.065 *in* wall) upstream window tubes which are in turn soldered to the cell block.

Since all the components are made of aluminum it is necessary to plate them before soldering. The final components were copper plated before assembly.

The cell block components have been pressure tested hydrostatically at Jefferson Lab. We chose the thinnest beer cans for the pressure burst test. Results are listed in the summary table. Upstream windows have been tested to similar pressures. Finally, the entire completed cell block assemblies were pressurized to 85 PSID with helium gas. A summary of the testing program to date is presented in Table 3.1.

Pressure Relief

The gas handling and controls systems have been designed to prevent excessive pressure build up in the system in order to protect the target cells from rupture.

Object	P (PSIG)	thickness (in)	size	test method
Can	55	0.003	short	test (J)ig, (D)estructive
Can	80	0.0035	short	(J), (D)
Can	80	0.0035	long	(J), (D)
Can	60	0.0038	long	(V)acuum, (D)
Can	85	0.0039	long	(V), (D)
Window	110	0.028		(J),(D)
Window	125	0.028		(J),(D)
Window	125	0.028		(J),(D)
Window	115	0.028		(J),(D)
Window	147	0.028		(J),(D)
Window	150	0.028		(J),(D)
Complete Blocks	85			(V), Non-Destructive

Table 3.1: A summary of the early cell block pressure test data.

In the event that the pressure in the system begins to rise there are multiple vent paths to release it. The first line of defense is the recovery tank. The second line of defense is a small orifice solenoid valve which is slaved to a pressure transducer. This valve, CSV28 for H₂ and CSV57 for D₂, is normally controlled by the limit output of the computer (via a VME based relay) readout of the pressure transducer that views the target relief line, PT131 for H₂ and PT140 for D₂. The valve itself is mounted in the fill line relief assembly. The separation of the valve from its controlling pressure gauge should provide some dampening of the response and the small orifice of the valve also ensures that it will be able to make pressure adjustments gently if need be. There is a separate relief valve on the fill side of the target, CRV30 for H₂ and CRV59 for D₂. This relief is mounted in parallel with the small orifice solenoid valve. Right on top of the cryocan, on the return side of the target, there is a large size (one *in*) relief valve. All target pressure reliefs are connected to the nitrogen vent line of the Hall A superconducting magnets. This is a 3.5 *in* diameter copper pipe which is filled with nitrogen gas at atmospheric pressure. Thus any vented target gas is placed in an inert environment until it is released outside of Hall A. Each gas tank has one relief valve and one rupture disk (CRV43 and CRD44 for hydrogen, and CRV72 and CRD143 for deuterium).

In addition to the reliefs on the gas handling system described above, the scattering chamber itself has a four-*in* one PSIG relief, VRV01. This is the path that the hydrogen will take in the event of a cell failure.

The target pressure reliefs are summarized in Table 3.2.

Scattering Chamber Vacuum Failure

The scattering chamber will be leak checked before service but obviously the possibility of vacuum loss cannot be eliminated. The most likely sources of vacuum failure are:

Name	Target	Location	Diameter (<i>in</i>)	Pressure (PSIG)
CSV28	H ₂	FRA	0.125	40
CRV30	H ₂	FRA	0.5	40
CRV82	H ₂	RL	1	40
CRV43	H ₂	TANK	1	55
CRD44	H ₂	TANK	1	55
CSV57	D ₂	FRA	0.125	40
CRV59	D ₂	FRA	0.5	40
CRV64	D ₂	RL	1	40
CRV72	D ₂	TANK	1	55
CRD143	D ₂	TANK	1	55
CRV35	He	RL	1	40
CRV01		SC	4	2

Table 3.2: A summary of the pressure relieving devices on the hydrogen/deuterium targets and the scattering chamber. FRA is an abbreviation for Fill Line Relief Assembly. and RL is an abbreviation for Relief Line. SC stands for Scattering Chamber.

Spectrometer Windows Initially the scattering chamber will have two aluminum windows, one for each side of the beam line.

Target Cell Failure This is a multiple loop system. If a target cell fails, the remaining targets will have their insulating vacuum spoiled.

The two spectrometer windows are both made from aluminum. Each window is seven *in* high and subtends 170 ° on the 43 *in* outer diameter of the scattering chamber. This window is made of 0.016 *in* thick 5052 H34 aluminum foil.

The scattering chamber was evacuated (and cycled several times) with both windows covered by the same 0.016 *in* material. The foil forms regularly spaced vertical ridges when placed under load. The window had an inter-ridge spacing of 3 inches. If the window is treated as a collection of smaller rectangular windows which have the full vertical height of 7 inches and the inter-ridge spacing as a width, then stress formulas predict that the 0.016 *in* material would reach ultimate stress at a pressure higher than 35 PSI. There is a gate valve between the scattering chamber and the beam entrance (exit) pipe. Both valves will be closed automatically in the event that the chamber vacuum begins to rise and an FSD will be caused (this is done via a relay output of the scattering chamber vacuum gauge). If either valve is closed an FSD will result.

In the unlikely event of a catastrophic vacuum failure, it is important that the relief line of the targets be sized such that it can handle the mass flow caused by the sudden expansion of its cryogenic contents due to exposure to the heat load. A calculation has been performed which models the response of the system to sudden vacuum failure. That calculation indicates that the relief plumbing is sized such that the flow remains subsonic

at all times and that the maximum pressure in the cells remains well below their bursting point.

The calculation was performed by following methods in an internal report from the MIT Bates laboratory [7]. The formulas and algorithm in the report were incorporated in two computer codes and those codes were able to reproduce results in the report (hence they represent an accurate implementation of the Bates calculation).

The calculation can be logically broken into two parts. First, the mass evolution rate is calculated from geometric information and the properties of both the target material and vacuum spoiling gas. The principal results of this first stage are the heat transferred per unit area, q , the boil off time, t_b , and the mass evolution rate, w . Second, the capability of the plumbing to handle the mass flow is checked. The principle result of this second step is the maximum pressure in the target cell during the discharge, P_1 .

The formula involved will not be repeated (readers are referred to the Bates report for detail). The information that was used as input to the calculation is given in tables 3.3, 3.4 and 3.5.

For the calculation of the boil off rate the target was split into two pieces: the cells plus cell block, both aluminum; and the heat exchangers plus the connecting plumbing, all steel. The mass evolution rates for the two pieces were then added in order to find the total mass flow rate.

Fluid and Phase	Property	Symbol	Value
Hydrogen/Liquid	Temperature	$T(K)$	22
	Density	ρ (kg/m ³)	67.67
	Specific Heat	C_p (J/(kg K))	11520
	Enthalpy of Vaporization	H_v J/kg	428,500
	Temperature	$T(K)$	22
Hydrogen/Vapor	Density	ρ (kg/m ³)	2.4991
	Viscosity	μ (kg/(s m))	1.29×10^{-6}
	Specific Heat	C_p (J/(kg K))	13,550
	Thermal Conductivity	k (W/(K m))	0.02
	Volume Expansivity	β K ⁻¹	0.00366
Air	Temperature	$T(K)$	273
	Pressure	P (Torr)	760
	Density	ρ (kg/m ³)	1.224
	Viscosity	μ (kg/(s m))	1.8×10^{-5}
	Specific Heat	C_p (J/(kg K))	1005
	Thermal Conductivity	k (W/(K m))	0.0244
	Volume Expansivity	β K ⁻¹	0.00367

Table 3.3: The properties of the gases used to calculate the heat transferred to the target during a catastrophic vacuum failure.

Quantity	Cell Block	Piping	Heat Exchanger	Total
D	2.5 in (0.063 m)	1.5 in (0.038 m)	7 in (0.1778 m)	
k	55 W/(K m)	6.5 W/(K m)	6.5 W/(K m)	
A	0.146 m ²	0.185 (m ²)	0.216 m ²	0.510 m ²
V	0.001 m ³	0.0019 (m ³)	0.002 m ³	0.0054 m ³
x	0.004 in (0.0001 m)	0.065 in (0.00165 m)	0.12 in (0.003 m)	
q	14903 W/m ²	10526 W/m ²	11235 W/m ²	
t _b	26.78 s	28.29 s	23.89 s	26.3 s
w	0.0038 kg/s	0.0045 kg/s	0.0056 kg/s	0.014 kg/s (0.03 lbs/s)

Table 3.4: The geometric quantities needed for and the results of calculations of the mass evolution rate after a catastrophic vacuum failure.

The calculation of the pressure drop includes all the plumbing up to the large relief valve. The calculation assumes that all the mass flow is carried out the relief side of the target gas handling system (no flow out of the fill line reliefs). The friction factor for each diameter was taken from a Moody plot. A typical value was $f = 0.017$. The effective K values, K_{eff} , were adjusted to the average tube inner diameter which was taken to be 0.71 in. The final K_{eff} value was 40. The minor losses are from bends, expansions and contractions in piping.

The final result shows the cells subjected to 58 PSIA during the boil off, which is comparable to the 75 PSIA pressure that the assembled cell blocks were tested at, and is significantly below the tested pressure of the cell components.

The scattering chamber has a volume of about 2,100 l with perhaps an additional 200 l of volume in the bellows and the cryo can. If one target cell were to rupture and the chamber were unrelieved, the chamber pressure would rise to about 2 Atm. It takes approximately 150 seconds to bring 5 l of 22 ° K hydrogen to room temperature by conductive heat transfer with the scattering chamber walls. In order that the maximum pressure in the chamber stay near one atmosphere, it is necessary to vent one half of the target mass in approximately one half of the total expansion time. Therefore the relief valve for the scattering chamber should be capable of venting about three grams per second at a low pressure difference (say two PSIG). If one considers the case where all three targets fail at once, the vent must be capable of handling three times that amount. A four in diameter relief valve placed near the top of the scattering chamber should be capable of handling this rate. A rise in the chamber vacuum will stop the beam, FSD, and cause the gate valves on either side of the scattering chamber to close.

In the unlikely event that a line which carries helium coolant were to rupture the four in chamber relief valve is capable of handling the full coolant flow rate.

Inner Diameter	Length	K (K_{eff})
0.44 in tube	10 ft	4.64 (31.5)
0.88 in tube	10 ft	2.32 (0.98)
Quantity		Value
Minor Losses		7.4
K_{eff}^{total}		40
Average Diameter		0.71 in
xmax		0.890
w_{sonic}		0.065 lbs/s
m		0.323
x		0.748
P_2		14.7 PSIA
P_1		58.3 PSIA
P_1		43.6 PSIG

Table 3.5: Tubing sizes, and other information needed to analyze relief line response. The mass flow rate was 0.03 lbs/s.

3.2.3 Temperature Regulation

This is really more an issue of target stability than one of safety. However, a target with a carefully regulated temperature will presumably not undergo worrisome pressure changes.

Each target contains four quality temperature measurements, two Cernox resistors and two hydrogen vapor pressure thermometers. The primary temperature regulation is done with a dedicated temperature controller (an Oxford ITC-502) which slaves a heater (the "low power heater") to the temperature read by one of the Cernox resistors. This is a three parameter control loop (Proportional, Integral and Differential Control or PID).

In addition, the return temperature of the target systems coolant gas is used to regulate the supply of coolant from ESR.

Finally, the heat load from the beam will be compensated in the "active" target loop by use of the high power heater. This is not a true regulation but rather a one for one replacement of the beam load should the beam disappear for whatever reason. The beam load is calculated from the target length, the beam current as read from a current monitor and the target material.

Excursions of the target temperature outside acceptable limits will cause the control system to take action. Finally the redundancy of temperature measurements can be used by the control system to pick up the failure of a sensor or its readout channel. A more complete discussion of target temperature regulation is available in Reference [8].

Target Freezing

Solid hydrogen is more dense than the liquid phase, so freezing does not endanger the mechanical integrity of a closed system. The chief hazard is that relief routes out of the system will become clogged with hydrogen ice, making the behavior of the system during a warmup unpredictable. However, since we are using 15 K coolant, while the hydrogen freezing point is about 13.8 K, the hydrogen target should not get frozen. The freezing point of deuterium is higher than that of hydrogen and higher than the temperature of the gas used for cooling (15 K). There is a chance that the deuterium target can freeze.

The coolant flow through the three target heat exchangers is connected in parallel for the three target loops. The entire target system will be run so that it represents a constant heat load on the ESR. For instance, the ESR will deliver a constant mass flow of helium cryogen at a constant temperature, about 15 K, and the coolant will be returned at an approximately constant but higher temperature, usually about 20 K.

The targets are always temperature regulated by temperature controllers. Also a high power heater will be in the PID loop to compensate any large temperature fluctuations to keep the temperature constant. In the unlikely event that the target temperature drops too low, an alarm will sound and the target operator will turn down the corresponding J-T valve(s).

3.2.4 ODH

The total volume of the targets is relatively small, with the entire scattering chamber containing only 9,000 STP l of target fluid when all three targets are full. As the scattering chamber is located in the middle of Hall A (i.e. not in a confined area) and the total Hall A volume is 40,000 m^3 , the ODH hazard is minimal.

3.2.5 Controls

The target controls have been implemented with the EPICS control system and with hardware very similar to that employed by the accelerator. The basic control functions reside on a VME based single board computer. The graphical interfaces to the control system use a PC, and also require the Hall A Hewlett Packard, HP, computer for control (HAC) to be present as well.

All of the instrumentation for the target is downstairs in Hall A. Most of the equipment (in fact all of the 120 V AC equipment) is on an Uninterruptable Power Supply, UPS. The items whose power is not on UPS are:

- The scattering chamber vacuum pumps and the gas panel backing pump
- The target lifting mechanism
- The target circulation fans.

This is a 7 kVA zero switching time UPS which is dedicated to the target. The PC, HAC and the counting house target X-terminal are on Uninterruptable Power as well. The targets dedicated UPS provides 18 minutes of power at full load (or 50 min at one half load). The status of the UPS, online or offline, is read by the control system and after ten minutes the control system will initiate an orderly shut down of the targets.

The principal functions that the control system performs are:

Pressure Monitoring The pressure at various places in the system is monitored and alarm states are generated if a transducer returns a value that is outside user defined limits. High pressures will cause the small orifice solenoid valve to open and cause an FSD.

Temperature Monitoring The temperature of the target is read from resistors and vapor pressure bulbs and alarm states are activated when any temperature sensor returns a value outside the user defined limits. High temperatures will cause an FSD to occur.

Temperature Regulation The control system allows the target temperature to be regulated. In the default operating scenario this regulation is performed by a stand alone temperature controller.

Solenoid Valve Control The gas systems have a number of solenoid valves that must be switched.

J-T Valve Control The flow of coolant through the heat exchangers is controlled by a set of J-T valves. These valves control the coolant helium flow through the three loop heat exchangers and the precool heat exchanger.

Circulation Fan Monitoring and Control The fans which circulate the target fluid are monitored (current, voltage, frequency). The voltage supplied to the fans is adjustable and alarm states can be set on out of range frequency, voltage or current values.

Vacuum Monitoring The scattering chamber vacuum is monitored by the control system. Unacceptable values will generate an FSD and close the upstream and downstream scattering chamber valves.

Target Lifter The target lifting mechanism is controlled by the computer. This allows one to place the desired target in the beam.

3.3 Authorized Personnel

The principle contacts for the cryogenic targets are listed in table 3.3. Every shift must have a trained target operator whenever the cryogenic targets contain liquid. These operators are trained by one of the “experts” listed in the table and certified by J.P. Chen.

Component	A Staff	#	Outside Group	#	Remark
Chamber Vacuum	Ed Folts	7857			Or Technician On Call
Cryogenic Target	J. P. Chen	7413			
	M. Kuss	5064			
	J. H. Mitchell	7851			
			M. Seely	5036	Target Group
			C. Keith	5878	Target Group
ESR			CHL	7405	Cryo Group
ESR			Cryo on Call	MCC	

Table 3.6: Contact Personel for the Cryogenic Targets and Scattering Chamber

Additional documentation on the targets and the target controls is available from J.P. Chen. In particular, reference [8] is highly recommended.

3.4 The Waterfall Target ^{5 6}

The waterfall target system provides a target for experiments on ^{16}O (see figure 3.1). The conceptual design of the waterfall target system for Hall A is very similar to the one used at Saclay [9]. The thickness of the waterfall target can be modulated by changing the pump speed; this adds flexibility to the system and allows the user to choose the best value according to the wanted resolution and luminosity.

The hydrogen in the water can be used for calibration purposes. Elastic scattering from the hydrogen in the target can be used to measure and monitor the target thickness. The counting rate in the elastic peak is directly proportional to both the beam current and the target thickness.

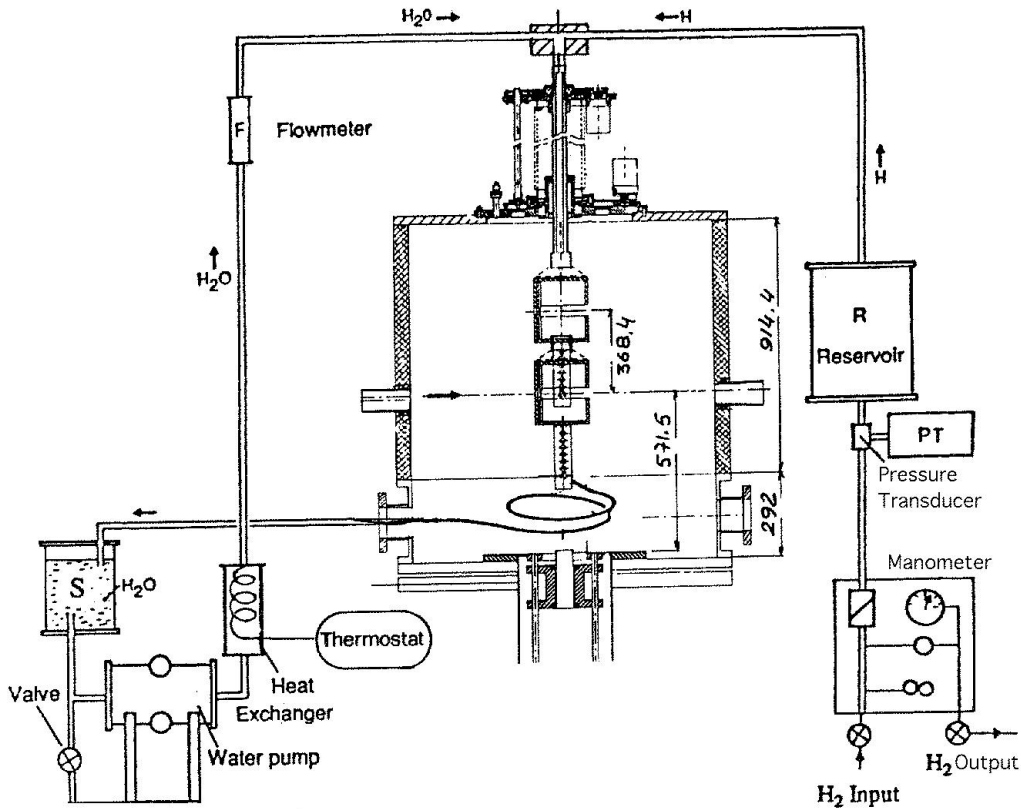


Figure 3.1: The target system.

The waterfall target can be single foil or multi-foils according to the need of the particular experiment. In fact, a modified version of this target has been built and used for experiments at NIKHEF (a $\sim 150 \text{ mg/cm}^2$ single-foil and a three-foil one $\sim 60 \times 3 \text{ mg/cm}^2$). The target built for Jefferson Lab Hall A for the two commissioning

⁵ CVS revision Id: waterfall-target.tex,v 1.1 2003/06/06 17:09:04 gen Exp

⁶ Authors: Dr.No <mailto:????@jlab.org>

experiments on ^{16}O (E89003 and E89033) is a three-foils one with thickness ranging from $\sim 130 - 200 \text{ mg/cm}^2$ for each foil, depending on the pump speed.

The main components of the target system are:

1. The waterfall target container, also referred to as “target cell” in this document;
2. The solid target ladder and the solid targets;
3. The hydraulic system;
4. The gas system;
5. The movement system;
6. The slow-control system.

The waterfall foils are produced inside the waterfall target container, which is mounted in the standard Hall A scattering chamber.

The water, continuously pumped from a reservoir, goes through a heat exchanger into the target zone, and then back into the reservoir. All parts in contact with the water are made of stainless steel. In the target zone, the water pressed through a system of slits and holes and guided by the stainless steel bars forms one or more flat rectangular films, which are stable due to the surface tension and to the adherence to the guiding bars.

The thickness of the foil(s) is (to some extent) a function of the pump speed which determines the flow rate. Once the foil is formed (there is a minimum value of the pump speed/flow rate for this, depending on the particular target) the thickness increases with the pump speed. The maximum pump speed depends essentially on the dimensions of the slits and holes the water passes through.

An absolute calibration of the target thickness as a function of the pump speed needs to be done before the experiment. One way of measuring the absolute target thickness is to measure the raw counting rate in the spectrometer.

The target used for E89003 and E89033 was at a fixed angle during the experiments. Therefore the waterfall target container is designed as a box with dimension of $630 \times 68 \times 8 \text{ mm}^3$.

The entrance and exit windows of the target cell are circular (40 mm in diameter) and are made of gold-plated Be (75 μm thick) (Fig. 3.2, 3.3). Scattered particles go through the ‘lateral’ windows, made of stainless steel (25 μm thick, dimension of $320 \times 8 \text{ mm}^2$). Some schematic views of the target container are shown in Figures 3.2, 3.3, 3.4 and 3.5.

The three foils are parallel and identical. Each foil is 12 mm wide, guided by two poles each of 2 mm by 2 mm cross-section. In the direction normal to the target, the foils are 22 mm apart. The normal direction of each foil is 30° with respect to beam line, and the normal direction points towards H-arm. The center of each foil is shifted 1 mm along the foil direction and towards E-arm, see Figure 3.3. The tolerance of the machining is less than 0.2 mm.

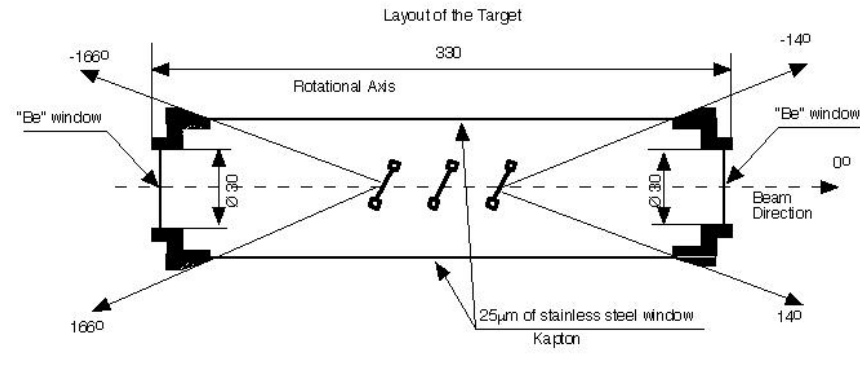


Figure 3.2: A cutaway of the waterfall target cell.

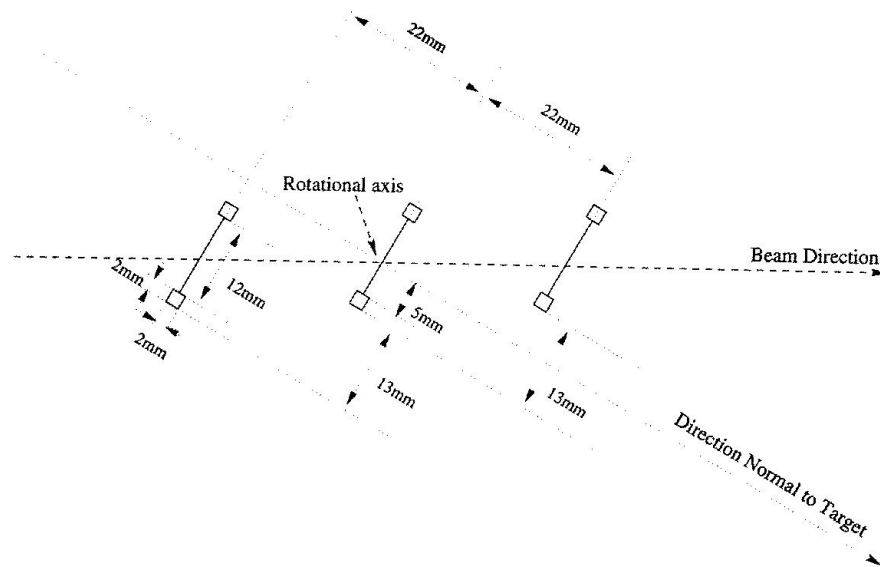


Figure 3.3: Detailed view of the 3-waterfoils geometry.

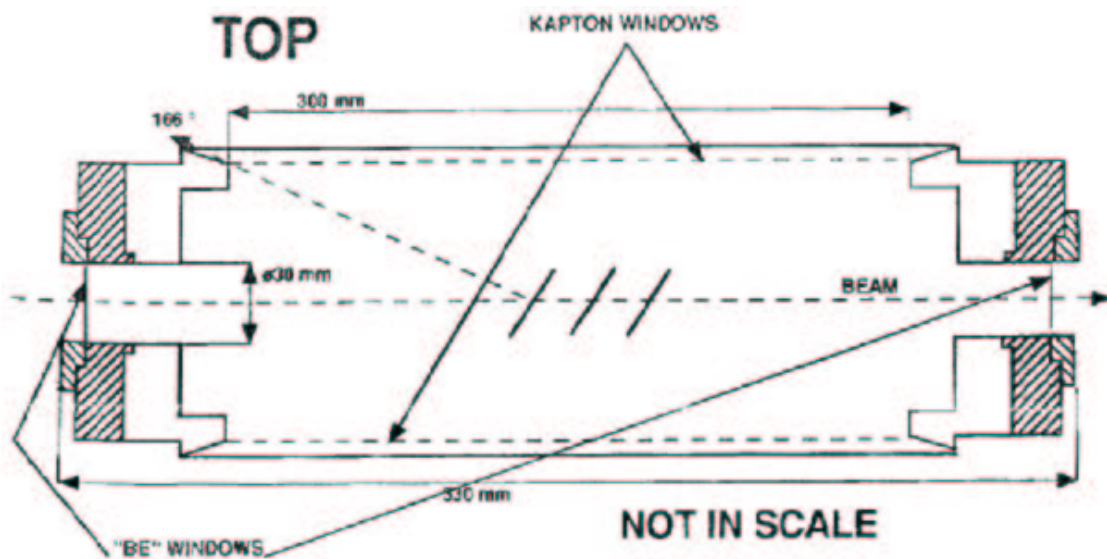


Figure 3.4: Cutaway view of the waterfall target container.

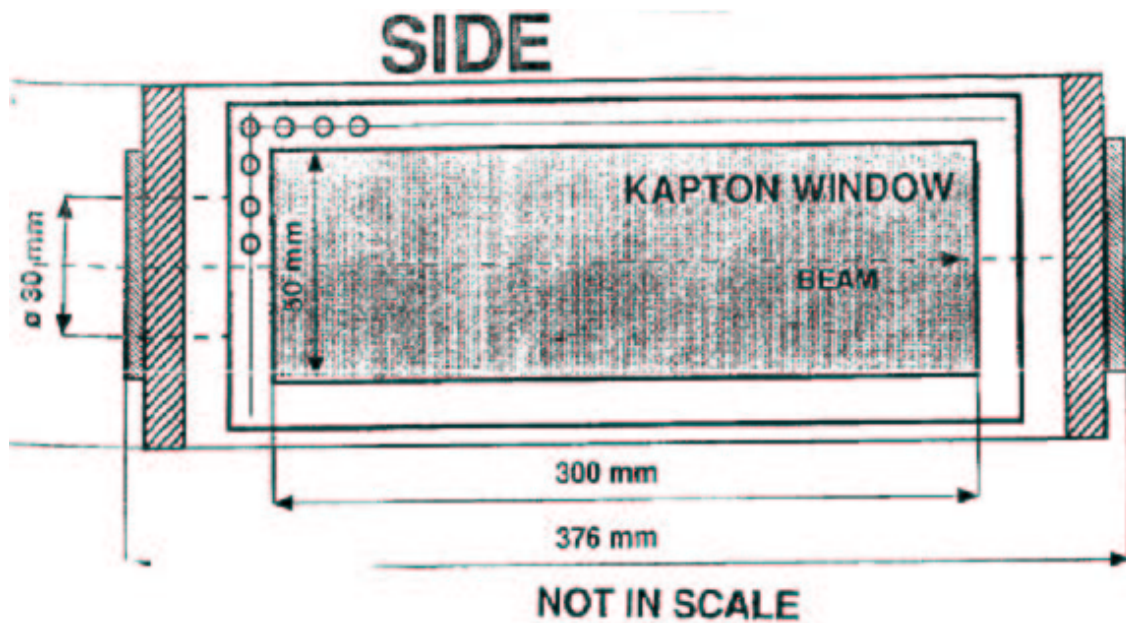


Figure 3.5: Side view of the waterfall target container.

A solid target ladder is attached to the bottom of the waterfall target container, which holds up to 5 solid targets. The water coming back to the container goes through two cylinders in contact with the side of solid target holders, providing some cooling for solid targets.

3.4.1 The hydraulic system

The hydraulic system is a closed circuit (loop), see Fig. 3.1 and 3.6. Water is pumped from a stainless steel water reservoir (or tank) to the target, and then back to the tank through stainless steel tubes. In order to produce a stable film, a gear pump, magnetically coupled to a dc motor, is used.

A tachometer which is on the pump axis measures the pump speed (turn/min), and a flowmeter, which is placed before the entrance of the scattering chamber, measures the flow rate. The set voltage is also read, although it is redundant. These parameters can be used to monitor the target thickness stability.

3.4.2 The gas system

The gas system, connected with the hydraulic system, is designed to pump gas into the waterfall target container to reduce background. Normally hydrogen gas is used. The gas system is made of a load and discharge tube circuit to allow the removal of the air by flushing the hydrogen into the target cell (and the water reservoir). Once the system is full, the circuit will be closed by electro-valves.

3.4.3 The movement system

The waterfall target and the solid target ladder can, by design, both be rotated around the central axis of the scattering chamber and be moved vertically to change the target at the beam position. This is done by a mechanical system schematically shown in Fig. 3.1, which consists of step motors and absolute optical encoders whose precision is 0.1 mm and 0.1 degree. For E89003 and E89033 experiments, the rotation motion of the target is not required and thus has been disabled to prevent accidental change of the target orientation.

3.4.4 The slow-control system

The slow control system consists of two Macintosh computers, two VME crates, an ADC, a DAC and an electronic circuit. It handles both the data acquisition and the control of the target system. The layout is shown in Figure 3.7.

Each Macintosh computer is hosted by one VME crate. The two computers are interconnected via an optic ethernet line (Fig. 3.8, 3.9). The first one (also called MacA) is in the hall. This is the Master. It controls the electronics directly with the slow-control program H2OCEBAF97 written in Labview. The second one (called MacB)

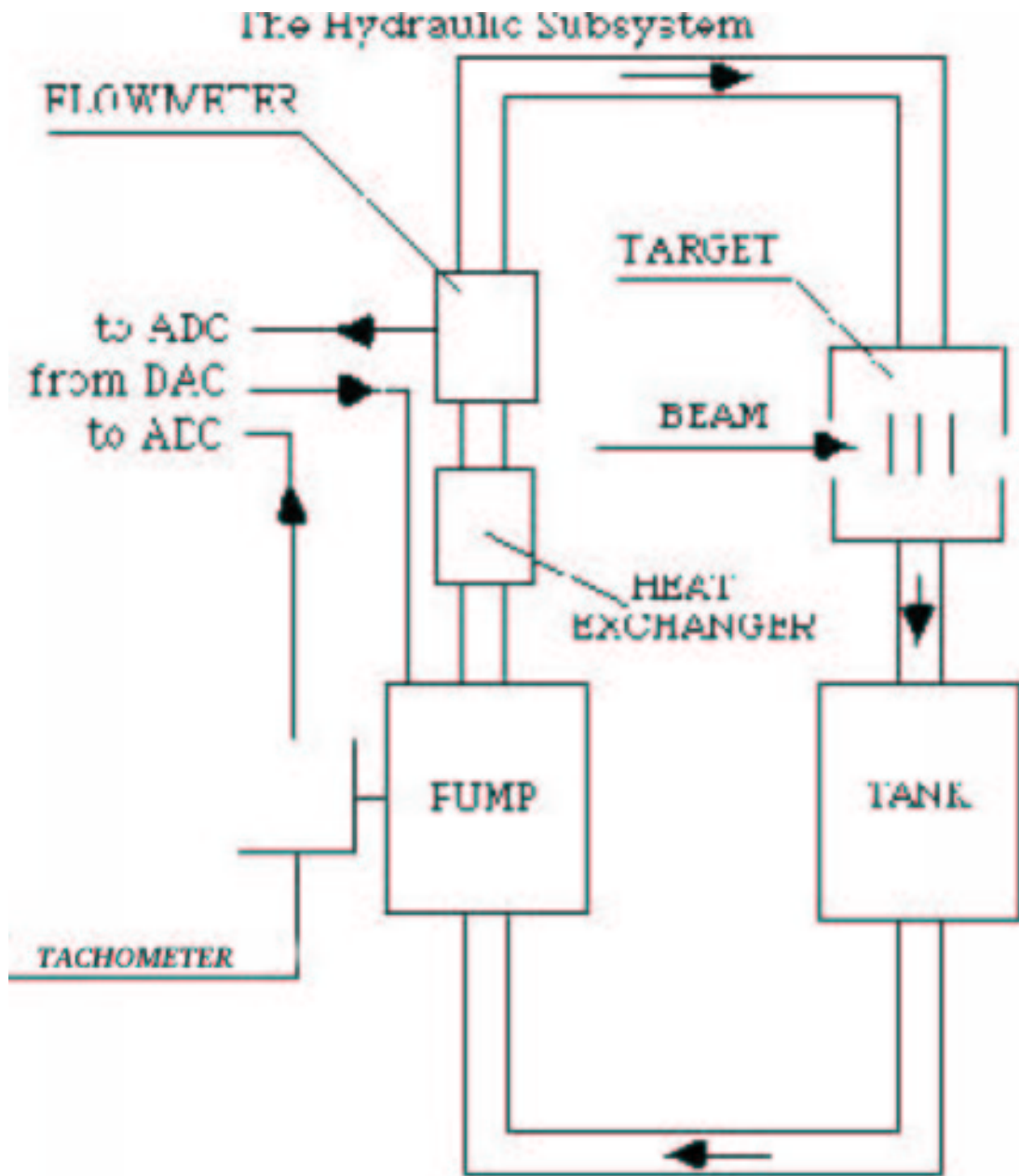


Figure 3.6: The Hydraulic system: a schematic view.

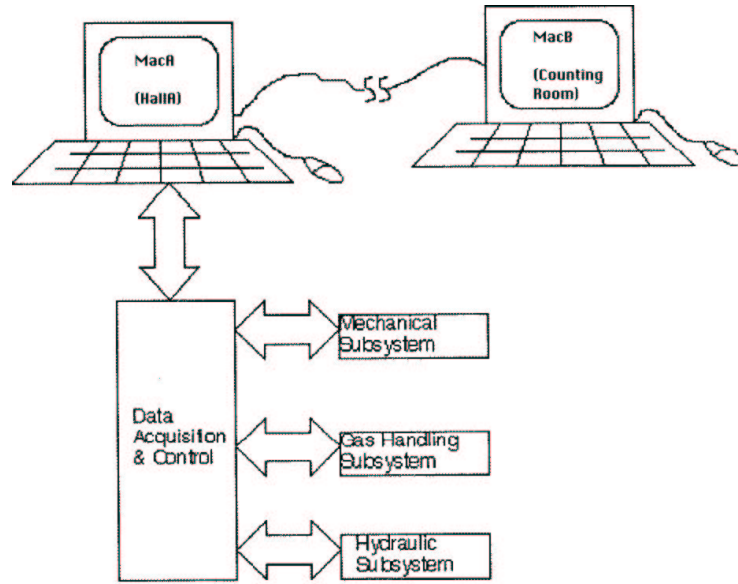


Figure 3.7: Schematic view of the whole system.

is a slave, and is located in the counting house where it controls the target system through MacA.

Some of the controls and monitoring can also be done manually. This provides an independent way of controlling the target in case the computer control fails. The pump control and the display of the flowmeter and pump speed are duplicated in the counting house. The reading of the optical encoder can also be seen in the counting house through a camera. A manual command of step motors is in the Hall.

3.4.5 Authorized Personnel

One of the following people can be contacted for any waterfall target problem:

Name	Home Institute phone	E-Mail
Evaristo Cisbani	+39-6-49902847	Cisbani@vaxsan.iss.infn.it
Franco Garibaldi	+39-6-49902243	Garibaldi@Vaxsan.iss.infn.it
Stefano Colilli	+39-6-49902832	Colilli@vaxsan.iss.infn.it
Maurizio Lucentini	+39-6-49902232	Lucentini@vaxsan.iss.infn.it
Fabio Santavenere	+39-6-49902232	Santavenere@vaxsan.iss.infn.it
Massimo Gricia	+39-6-49902232	Gricia@vaxsan.iss.infn.it
Mauro Iodice	+39-6-49902235	Mauro@vaxsan.iss.infn.it
Guido Urciuoli	+39-6-4457165	Urciuoli@vaxsan.iss.infn.it
Salvatore Frullani	+39-6-49902234	Frullani@vaxsan.iss.infn.it
Roberto Perrino	+39-832-320504	Perrino@Le.infn.it
Antonio Leone	+39-832-320504	Leone@Le.infn.it

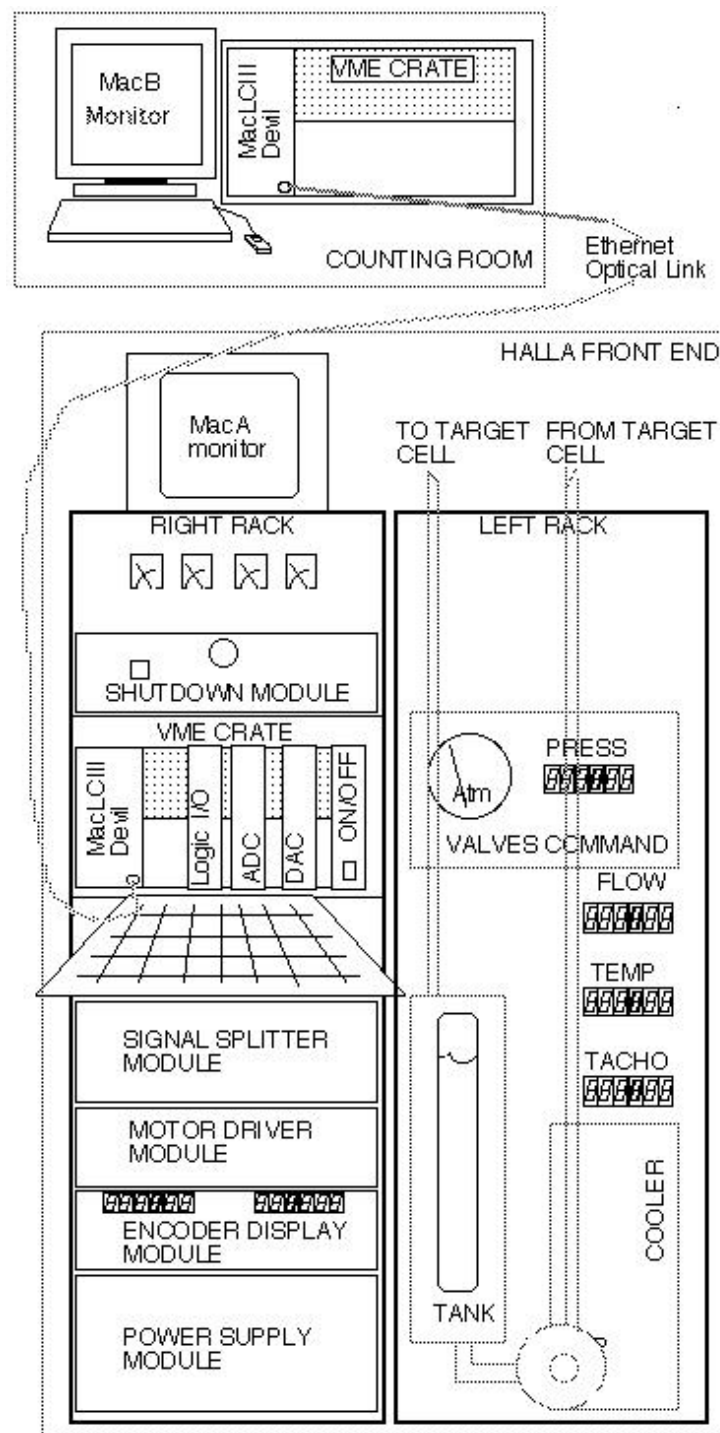


Figure 3.8: Layout of the slow control system.

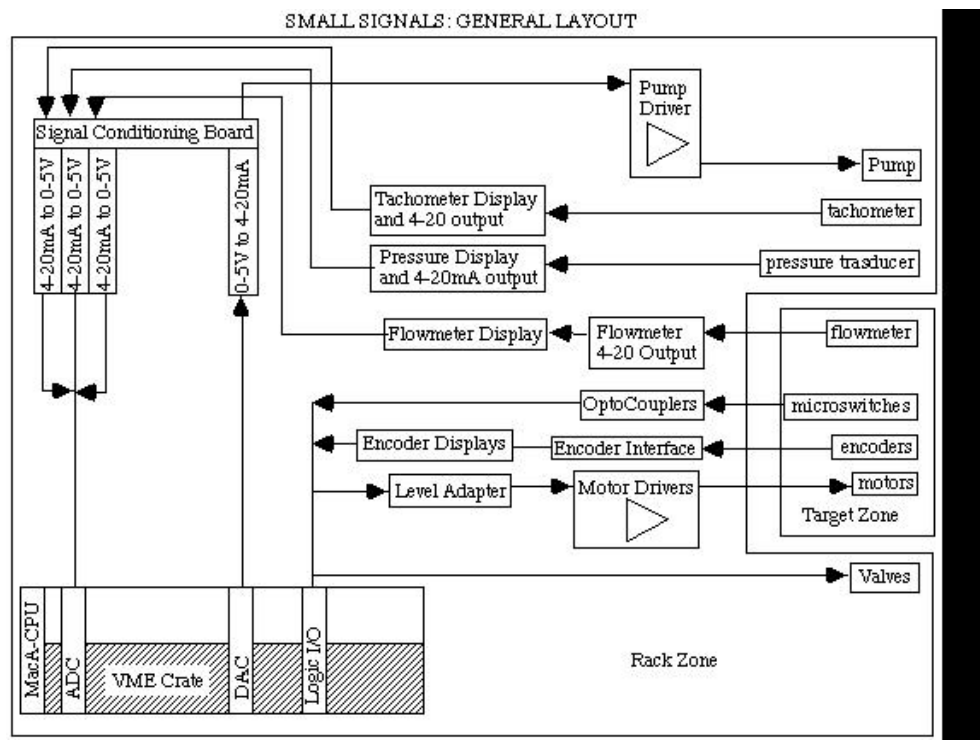


Figure 3.9: Signals layout

The phone at Jefferson Lab is x5794.

In absence of the forementioned people please contact: Meme Liang, Arun Saha, Ed Folts, James Proffitt or Mark Stevens, all of them at @Cebaf.gov

3.4.6 Safety Assessments

The following potential hazards have been identified:

The low voltage system

The system is supplied by 220Vac and 110Vac. There is a magneto-thermic and differential switch at the very first entrance of the power supply. All the lines at these voltages are kept inside the racks, and the plugs satisfy the European CE rules for these voltages. The supply for the single devices inside the racks is all at 5VCC, 12VCC, 24VCC, except for the pump which needs 110VCC and for the Motor Drivers, which need a special 80VCC voltage. A custom power supply unit has been built for this purpose, and this unit is kept in the so-called "Power Supply Unit" at the bottom of the left rack, together with the other supply units. The signal lines are low voltage ($\leq 12\text{VCC}$ the digital lines, 0-5V or 4-20mA loops the analog ones) and kept separated from the supply lines by using different connectors and separated cables. Optocouplers have been used for the microswitch line-in, isolated input lines have been used for the analog lines. A potential hazard outside of the racks, is the motor cables, which must be touched only by AUTHORIZED PERSONNEL and with the power supply switched off. An 80VCC/2A (square wave, duty cycle 0,5) current flows in these cables when motors are in stand-by mode. This current goes up to 7A (square wave, duty cycle 0,5) when motors are moving; these high power lines are everywhere kept separated from the low voltage lines. The pump power supply line is kept inside the racks, and in a position that cannot be reached unless opening the side panel of the right rack.

The gas system

This system is a potential hazard only if hydrogen is used. The volume is ~ 10 liters. The pressure is 1.02 atm. The target cell for gas tightening has been tested up to 2 bars. The gas transport tubes are made of stainless steel, 6 mm in diameter. The electro-valves are anti-deflagrant according to the USA regulations, working at low voltage (24V AC). All the power supplies for this section are kept separate in a different rack.

The default value for the valves, which is at the released position if power supply fails, is "closed". Regulating the pressure on the gas cylinder to 0.2 atm avoids the pressure in the target cell overriding this value even in the case of valve failure. Both the manual valve and the remote valve control require the operator to keep pressing the button either on the front panel of the right rack, or by using the mouse button on the corresponding icon from the computer, in order to keep the valve open. If the button is released, the valve will go back to the default value, i.e., closed.

Any leakage from the cell would be immediately detected by the scattering chamber vacuum measuring system. Leakages outside of the scattering chamber would spill in the surrounding atmosphere in the Hall. However, because of the small amount due to small

gas overpressure, this should not represent a potential hazard for the people working in the hall. In any case, there are two pressure transducers in front of the right rack; their values can be seen both in the Hall A directly on the panel, and in the Counting House on the computer, or on the display through the camera, which should reveal immediately if there is any leakage.

The water system

There are about 17 liters of pure water in the circuit. The water tank, the tubes, the target and the cell containing it, are made of stainless steel. The tubes are joined by "swagelok" connectors. The entrance and exit windows for beam passing through are made of 75 μm Be; the two side windows are made of 1 mil stainless steel.

The cell has been tested up to 2 bars for gas leaks. No water leakage is expected unless the windows of the target cell break. In this case some water, carrying some radioactivity, goes into the scattering chamber.

The calculations performed by Geoff Stapleton show that the radiological precautions necessary are rather low. The water should not leak into the hall drains. Measurements at convenient intervals will be made by the radiation control group on samples, to permit determinations of the radionuclides yields. In case of water loss or draining water, the radiation control group has to be informed to take precautionary measurements.

The slow control system

There are no significant hazards in working with this system, due to the low voltages and very small currents. However, one must switch the power off to the whole system before opening and working on the system. ONLY AUTHORIZED PERSONNEL are allowed to touch the signal lines.

The mechanical system

There are no particular risks in touching the mechanisms, except when the system is in motion. In this case one has to beware of the cog-wheel's movements, by keeping his hands away; for this reason, it is FORBIDDEN to touch the moving system when motors are moving.

3.4.7 Operating procedure

All the operations are handled by computers. Some of them can also be performed independently by mechanical switches (referred to as manually). In the following, the main window of the slow control program running on the MacA and/or MacB display will be referred to simply as the "main window".

Connection of MacB to MacA

The MacA and MacB communicate through the Timbuktu package, which implements the TCP/IP protocols over an Ethernet dedicated line. To make the connection, following procedure outlined below:

- Switch on the MacB computer (energize the VME crate).
- Run Timbuktu on the MacB; you can select it in the Apple (top-left) menu.
- Open the connection selecting the **CONTROL** button after you entered the TCP/IP number (129.57.188.20).
- Give the username **H2OCEBAF** and the password **WATER**.

The window that appears contains a ‘carbon copy’ of the MacA screen: the user in counting room can control all the operations of MacA by using the MacB mouse and keyboard as if the MacB user were using the MacA; **BE CAREFUL: the performance is reduced due to the connection: Be patient! wait for the screen to refresh after any action.**

Startup of the system

The system startup depends on the history of the shutdown:

After a normal shutdown

In the hall,

- Go to the right side of the right rack and push the green start button of the right box; you will hear a beeping sound;
- Go to the front of the left rack and push the green button near the *emergency* one;
- Wait for the MacA to be operative;
- Click on the *H2OCEBAF97* icon (the slow control program for the water target at CEBAF), which is almost in the center of the MacA desktop. The LabView application will run automatically and the slow control main window will be shown;
- Push the arrow button on the top-left side of this window in order to start the program.

The first time the program is run, after MacA power on, it initializes the electronic modules. Every time the program is run, it asks for a new initialization of the electronic modules. Answer YES; a small window with 4 buttons appears. Press all the buttons in order from top to bottom. When the initialization is done the main window comes back.

After an emergency shutdown

- Recognize the cause of the emergency, and fix it.
- Release the emergency button in the hall or in the counting house, depending on which one was used for the emergency shutdown, in order to restore its operation. The system will be energized and a beeping sound will be heard.

- Push the green button near the emergency red button. The beeping sound will be turned off.

System shutdown

The normal procedure:

- Go to the experimental hall;
- Close the program on the MacA; shutdown the MacA;
- Move to the right side of the *Right* rack and push the red stop button of the right box (the left box is not used).

The emergency procedure:

This procedure is really an EMERGENCY procedure; do not use it for normal operation. Push the *emergency* red button in front of the left rack if you are in the hall, or the one in the counting room on the top of the computer monitor. In order to restart the system follow the startup procedure described above.

Waterfall activating

- Check that the slow control program is running on MacA and optional on MacB;
- Check if the pump is on, and in case it isn't turn it on from the switch in front of the right rack or from the switch in front of "Pump Command Module" in the counting room
- Increase the pump speed to desired value in the main window of MacA or MacB (right side);
- Wait about 20 minutes to stabilize the water flow.

Empty target procedure

From the counting house: use the slide on the right of the main window of MacB to set the pump speed to minimum, then switch off the pump by turning off the switch on the front panel of the "pump Command Module" which is located over the MacB monitor;

or

In the hall: one can set the pump speed to minimum either from MacA by using the slide on the right of the main window, or use the button on the front panel of the right rack, and then turn the pump switch on the right rack to "off" position.

The reactivating of the pump needs to be done from the same switch used to deactivate it; see "Waterfall Activating Procedure".

Target movement procedure

After the slow control program H2OCEBAF97 is activated,

- Press the motor button on the bottom of the main window of the computer; a motor control window will appear;
- Select the type of movement (*up/down, rotation*);
- Select the target or the angle; the Move button should be activated if everything is O.K.;
- Press the Move button; a warning message reminds you to be sure of your action. *Be sure that the beam is off!!*
- During the movement watch the two displays showing the current position and the one to be reached.
- When the final point is reached, a message will inform you of the success of the operation. Otherwise a warning message will tell you about the faulty status.

(Eventual) gas flow operating procedures

The gas filling of the target cell, when empty, has to be done in Hall A: on the right rack there is a self-explaining panel. The *washing* button has to be pushed (for about 15 minutes) to open the inlet and outlet valves in order to allow the gas to replace the air which fills the target cell.

In order to refill the cell, in the case of very small leakages (remember that the pressure must be about 1.02 Atm), push the pressure bottom of the main window. The pressure control window will appear. The operation is self-explaining. Just remember that the gas flows only if you keep the button pressed.

Calibration of the movement system

For ‘normal’ operation the user does not need any additional information about the movement system. The following calibration tables (target and angle positions versus encoder values) are useful for checking purposes; notice that if the target changes, the calibration has to be performed again. The following values are OK for the waterfall, carbon, beryllium, iron target which was installed in July '96.

Target	Encoder Position
Water	17301
Up Survey	38528
Carbon	42949
Beryllium	47371
Iron	51792
Low Survey	56213

The vertical scale factor is: 1 encoder unit = 5.74 μm .

The angular correspondence is:

Angle	Encoder Position
0 degree	27361
30.533 degree	26479

that means: 1 encoder unit = 0.035 degree.

When a new calibration is required⁷ only the expert(s) is(are) allowed to perform the following steps:

- Go to the hall;
- Run the calibration program ("setlimits.vi") on MacA in order to allow the computer to get the limits of the movement ranges (up/down and rotation if enabled); this procedure takes several minutes;
- Rotate the target to two angles and take note of the encoder values;
- Write these value on a scrapbook;
- Select sequentially the 6 targets (waterfall and the solid ones) and take note of the encoders values;
- Note ALL the previous and new values in the logbook,
- Move.

3.4.8 Troubleshooting

Movement failure: automatic shutdown

If one of the 4 second-level microswitches (just after the first-level ones) is hit during the movement, the motor power supply will be turned off immediately. If this happens, a beeping sound will inform you that the motor movements are stopped and inhibited. To restore the operation,

1. Recognize the cause of the trouble (for example the MacA computer crashed), and try to fix it as much as possible (in the previous example restart the MacA and the slow control program);
2. Remove the inhibit; there is a switch in the left side of the *left* rack; switch it in such a way as to turn off the corresponding light, then push the green button in the front of the *left* rack, near the emergency button, in order to switch off the beeping sound. **At the same time check that the motors are not moving (watch the 2 encoder displays in front of the *left* rack);**

⁷particularly, a new calibration has to be done after the substitution of the complete target castle, if the vertical alignment values are changed

3. Now you can move the motor only manually: switch on the 80 volts manual motor power supply (the switch is in front of Power Supply Module, at the bottom of *left* rack);
4. Turn the remote/manual knob to manual position (the knob is in front of Motor Drive module, at the center of *left* rack);
5. Select the direction, opposite to the one which caused the alarm (the switches are in front of Motor Drive Module);
6. Handle the joystick carefully, **get ready to switch off the manual motor power supply if anything goes wrong.**
7. **As soon as the trouble has been fixed, restore the security, turning on the switch on the left side of the *left* rack (the corresponding red light must be on). This is the same switch of step number 2. If you forget this step the security microswitches will be disabled and you risk serious damage to the movement system.**

Emergency: Use of Movement System with the Cranks

If it is not possible, for any reason, to use the motors to move the target there is the chance of moving it manually, using some cranks. This procedure can be performed **ONLY BY AUTHORIZED PERSONNEL**, because of the **RISKS TO THE TARGET**. The procedure is the following:

- Remove the motors from their seats;
- Take the two cranks which are in the wooden box number 1, near the wall in Hall A;
- Mount the cranks instead of the motors;
- If the encoders are working, one can position the target by reading the encoder values on the display and matching the values with the look-up table which is in the manual;
- If encoders are not working, the alignment must be done by matching the signals on top of the scattering chamber.

Encoder substitution procedure

First of all, consider that the encoders are very delicate mechanisms, and must be carefully handled; please **NEVER** use hammers or similar tools unless you want to risk destroying them; moreover, do not apply torques directly on their axes, and turn them only by hand. For the substitution, execute the following procedure:

1. Switch the whole system off;
2. Remove the cable from the broken encoder;

3. Remove the cylindrical lead shielding which is around the encoder;
4. Remove the three screws at the base of the encoder, on the stainless steel ring;
5. Now you can remove the encoder.
It has its stainless steel ring fixed on the base;
6. Remove this ring from the encoder, by unscrewing it;
7. Take the spare encoder from the wooden box number 1, near the wall;
8. Without remounting the encoder, you must realign the target to the reference position ⁸, by turning the top of the scattering chamber with your hands and aligning the reference point with the alignment signs on top of the scattering chamber; this can be done manually, after removing the motor corresponding to that movement. **When you remove the vertical movement motor the target could drop down, which may severely damage the integrity of the target; for this reason you have to block the cog-wheels by putting something among the mechanisms before removing the motor. Be extremely careful when performing this procedure.**
9. Now connect the new encoder to the cable, and turn on the power supply to the system. Check the value of the encoder position, which readout is displayed at the bottom of the left rack: this value must match with 27361 (rotation) or 17301 (up/down) ⁹. If values do not match, then turn MANUALLY the encoder axis, until the display value is at the desired one. When done, you can remount the encoder on top of the scattering chamber.
10. Switch off the system;
11. Put the stainless steel ring back on the encoder, as it was mounted before;
12. Re-check the encoder value, and realign it if it is changed;
13. On top of the scattering chamber, in the place where the encoder must be mounted, you will see two pairs of cog-wheels. Turn gently the two wheels of the upper pair, one CW the other CCW, in order to charge the small spring among them; then, keeping this spring in charge, position the encoder back on its place, and fix it by putting back its screws.
14. Connect the cable;

⁸The reference position must be detected once when installing the target and once when checking the alignments of the reference points with the metric rulers on the top of the scattering chamber. Here we use the reference position, the waterfall target position and at zero degrees angle. Changing the target block, a new reference point must be detected.

⁹One single encoder step error means an offset error of about 0.04 degrees, or 0.006 mm.

15. Check again the encoder value reading: if it is still 27361 (rotation) or 17301 (up/down) you are OK, otherwise you must remove the encoder and repeat the operations from the step 9. When the value is correct, you can remount the shielding;
16. Re-connect the cables;
17. Turn the system on;
18. Check if everything is OK, by moving the target up-down (and CW-CCW if rotation is enabled) and watching the encoder reading values, which must change consequently: if everything is OK, then there is no need of a new calibration, and the system can work again; otherwise, you must understand which one of the above steps has failed, and go back to that starting point.

The water pump computer-control does not work

Check the following items:

- The switch above the MacB monitor must be in the ON position;
- The switch on the back of the MacB rack in the counting room must be in the REMOTE position;
- The pump speed switch in the front of the right rack in Hall A must be in the REMOTE position;
- The pump speed knob in the front of the right rack in Hall A must be at 60; notice that this knob should not be moved; it controls the maximum speed of the water pump. ¹⁰

¹⁰The scale is in %.

3.5 Polarized ^3He Target ¹¹ ¹²

¹¹ *CVS revision* Id: pol-he3.tex,v 1.2 2003/06/06 17:12:31 gen Exp

¹² Authors: Dr.No <mailto:????@jlab.org>

Chapter 4

High Resolution Spectrometers (HRS)

4.1 Overview ^{1 2}

The Hall A spectrometers and associated instrumentation are designed to perform high resolution and high accuracy experiments. The goal is to achieve a missing mass resolution of ~ 200 -500 keV to clearly identify the nuclear final state. An absolute accuracy of $\sim 1\%$ is also required by the physics program planned in the Hall, which implies $\sim 10^{-4}$ accuracy in the determination of particle momenta and ~ 0.1 mr in the knowledge of the scattering angle.

The instruments needed are a high resolution electron spectrometer (HRES) and a high resolution hadron spectrometer (HRHS), both with a maximum momentum capability matching the TJNAF beam energy, and large angular and momentum acceptance.

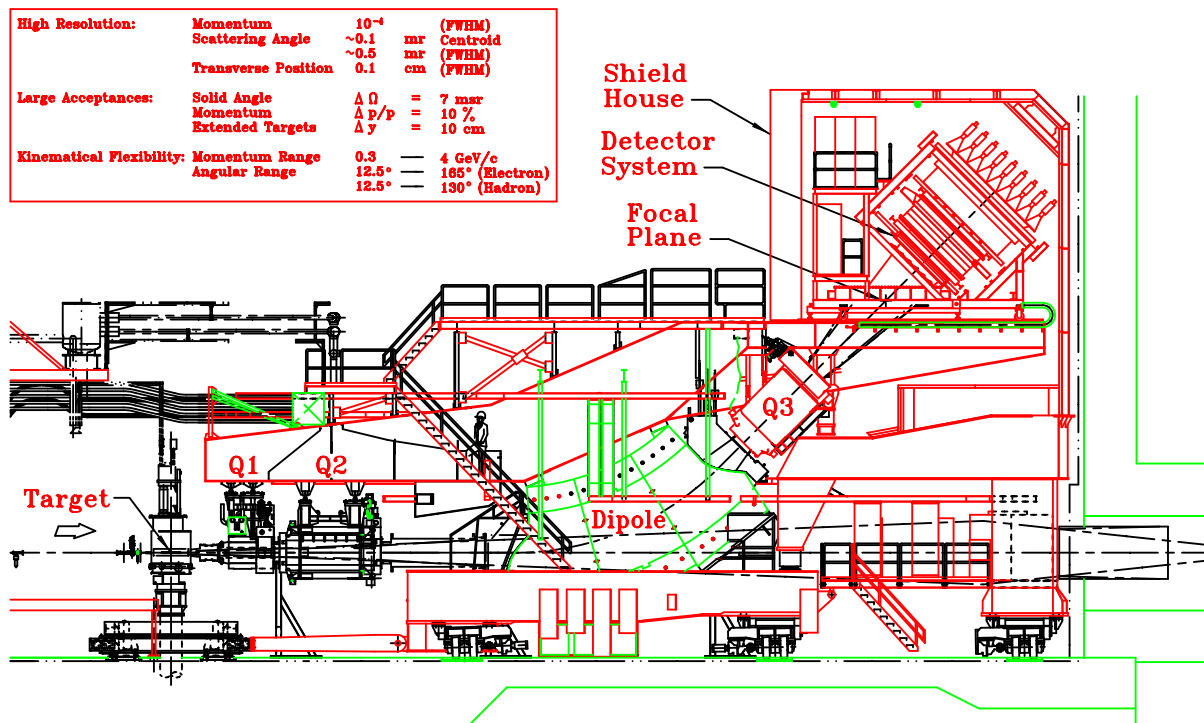
A layout of the 4 GeV/c High Resolution Electron Spectrometer is shown on Figures 4.2 and 4.1. Its main design characteristics are given in the attached table. The spectrometer has a vertical bending plane and 45° bending angle. The QQDQ design includes four independent superconducting magnets, three current-dominated $\cos 2\theta$ quadrupoles and one iron-dominated dipole with superconducting racetrack coils. The second and third quadrupoles of each spectrometer have sufficiently similar field requirements that they are of identical design and construction. The overall optical length, from target to focal plane, is 23.4 m. Optically, the HRHS is essentially identical to HRES. In fact the two spectrometers can be used interchangeably to detect either positively or negatively charged particles as needed by any particular experiment.

The support structure includes all system elements which bear the weight of the various spectrometer components and preserve their spatial relationship as required for 45° vertical bending optics.

The alignment and positioning system includes all the elements which measure and adjust the spatial relationship. The support structure consists of the fabricated steel

¹ CVS revision Id: hrs-1999.tex,v 1.1 2003/06/06 15:44:08 gen Exp

²Authors: J.LeRose <mailto:lerose@jlab.org>



11/5/96

Figure 4.1: A side view of the Hall A HRS spectrometer.

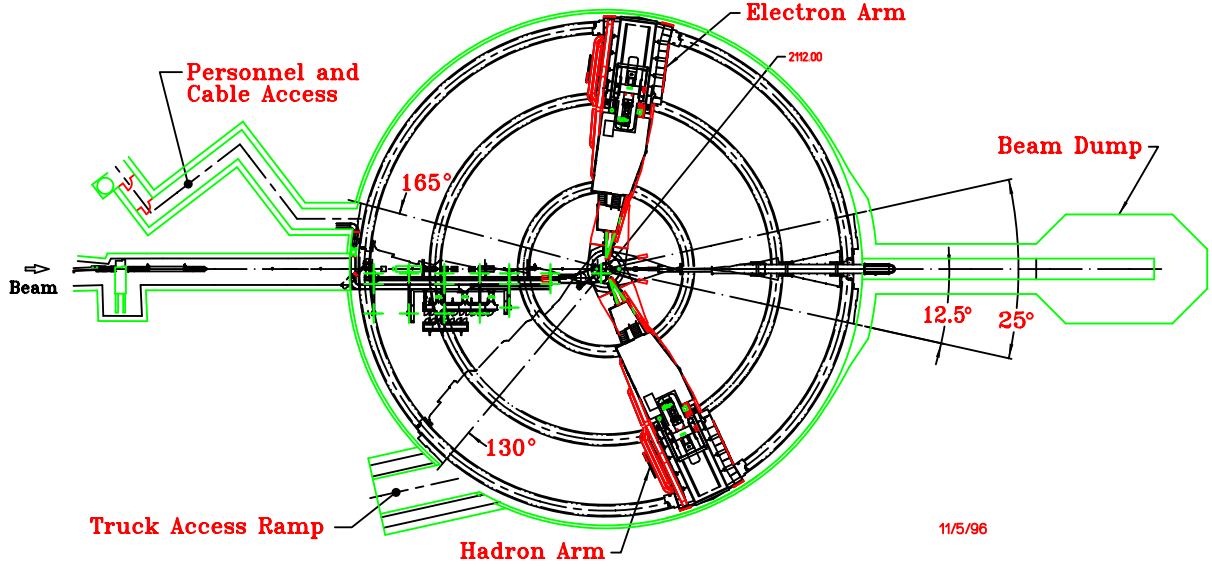


Figure 4.2: A bird's eye view of the Hall A end-station at TJNAF.

components which support the magnets, detector, shield house and associated equipment. It is composed of the box beam, which supports the outer elements in fixed relative position atop the dipole; the dipole support bracket, upon which the dipole rests on the jacks; the cradle, upon which the dipole rests through the vertical positioning system, VPS; and a portion of the shield house load through the inboard legs of the gantry; the gantry, which supports the shield house and the magnet power supplies; and the bogies, which support the cradle-gantry assembly and slide on the floor plates and provide the driving power to move the two spectrometer arms.

The detector package is supported on the box beam and is surrounded by the shield house. It must perform two functions, tracking and particle identification, PID. The most important capability of focusing spectrometers is measuring precisely the momenta and entrance orientations of the tracks. Momenta resolution of 10^{-4} is obtainable, consistent with the resolution of the incident beam.

A particle traversing the detector stack (Figure 4.3) encounters two sets of horizontal drift chambers (x,y) with two planes of 368 wires in each chamber. The track resolution is $\sim 100 \mu\text{m}$. From the chamber information both positions and angles in the dispersive and transverse directions can be determined. The information from these chambers is the principal input of the tracking algorithms.

The chambers are followed by a scintillator hodoscope plane designated S1. This plastic scintillator array provides the timing reference for the drift chambers, and is also used in trigger formation and in combination with a second hodoscope pair it can provide time of flight particle identification. These scintillators can also be used to perform crude tracking.

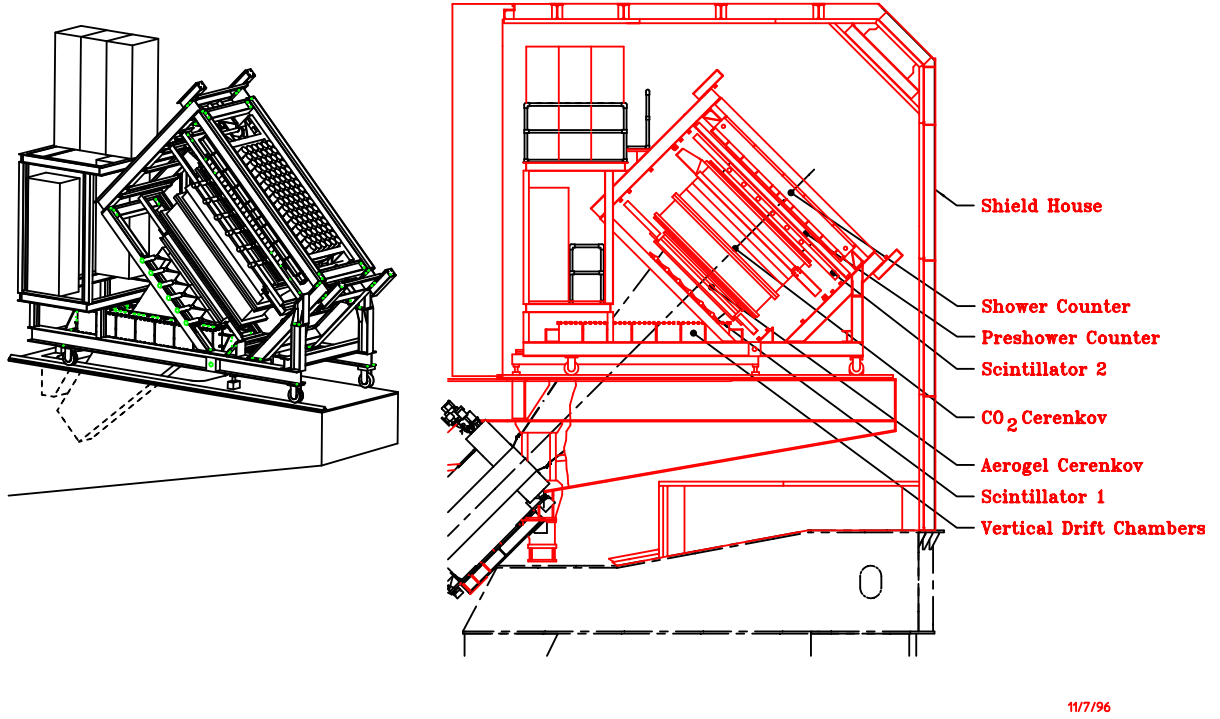


Figure 4.3: The electron spectrometer detector stack.

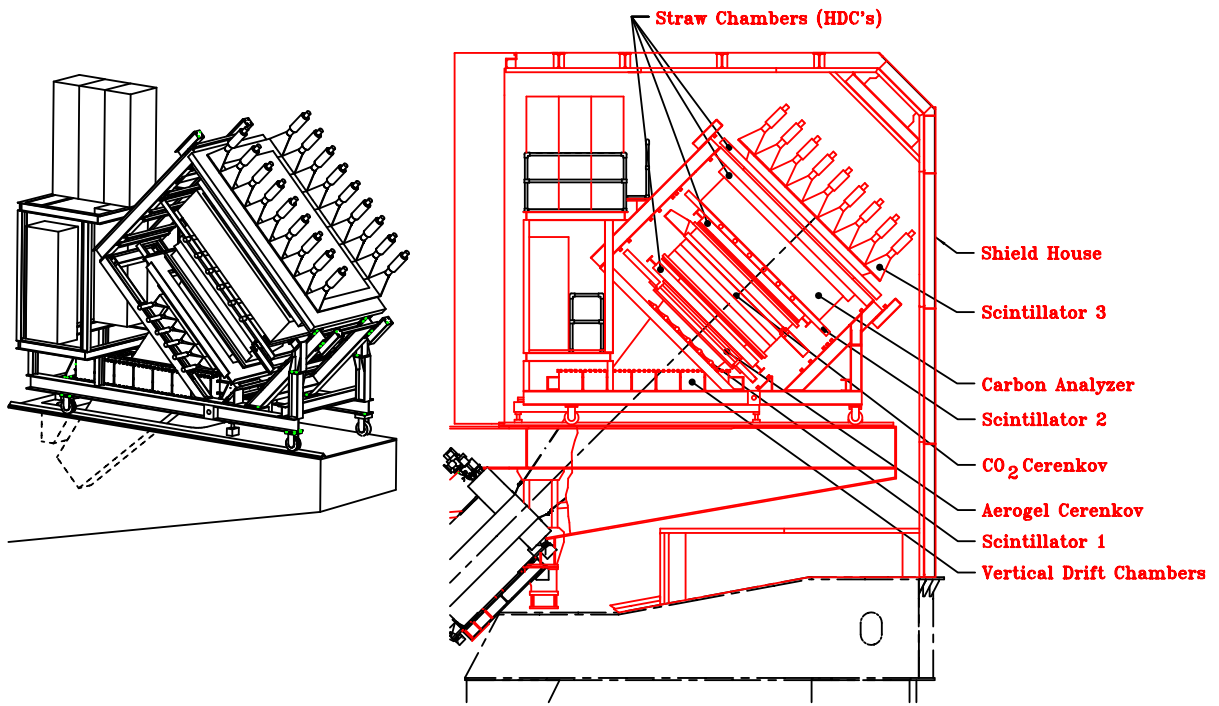
The next element encountered by a particle is a gas threshold Cerenkov detector. This is used for particle identification. In the hadron spectrometer this gas threshold Cerenkov detector can be swapped against an Aerogel detector, with a similar function.

The second hodoscope plane, S2, is located directly behind the gas Cerenkov. Its function is essentially the same as that of S1. In the hadron spectrometer an option exists to have this hodoscope pair be preceded by a third chamber, to improve tracking. Each of the two spectrometers have gas and Aerogel Cerenkov detectors which can be used when they are in electron detection mode.

The final elements in the detector stack on HRSE are the pre-shower and the lead glass shower calorimeter. This is used for energy determination and PID.

The hadron detector is shown schematically in Figure 4.4. It consists of two sets of (x,y) vertical drift chambers identical to those of the electron arm. The remaining part of the detection system is used to define the level 1 trigger, as well as for particle identification and timing. It consists of three minimally segmented planes of scintillation counters equipped with photomultipliers at both ends, and it includes Cerenkov counters (gas CO₂ and Aerogel).

In addition, a proton polarimeter is installed in the back of the detector package to measure the polarization of the proton using a segmented carbon analyzer up to 60 cm in thickness to allow measurements over a wide range of proton energies. A pair



11/7/96

Figure 4.4: The hadron spectrometer detector stack.

of front and a pair of rear straw chambers determine the incident and scattered angles, respectively. The third scintillation counter, located at the rear end, provides the trigger for the polarimeter. The polarimeter detectors are dimensioned to accept a 20° cone of scattered protons.

Several support systems are necessary in addition to the basic components mentioned above. They include gas supply systems for the wire chambers, high voltage supplies, readout electronics, a second level trigger, software for data analysis and testing, and a remotely controllable mechanical system.

As for the electron spectrometer, all detectors are mounted on a single rigid carriage along with their associated electronics. The FPP components are mounted on an FPP subframe for installation and removal as a unit. The trigger electronics are located next to the detectors, as for the electron arm.

To reduce the resolution degrading effects of multiple scattering, the entire interior of the spectrometer from the pivot to the detector hut is a vacuum vessel. The ends of this evacuated volume are capped by relatively thin vacuum windows.

As mentioned, subsystems will be discussed in more detail in the next three sections. The remainder of this section will describe some features common to the two spectrometers, then the following major sections will be devoted to the specifics that are not common.

4.1.1 Safety with Regards to the Spectrometer

The principle concern with the spectrometers is that they are large, and have associated vacuum, hydraulic, cryogenic and magnet systems all of which can be potentially dangerous.

The bogies which move the massive 1200 ton spectrometers must be carefully operated. Inspection of the wheels to ensure there is no debris which the wheels could ride over is mandatory. Similarly personnel need to be aware that the spectrometers are moving so that no one inadvertently gets trapped.

The vacuum systems associated with the spectrometers are essentially pressure vessels. Care should be exercised so as not to puncture the windows.

The magnets themselves are installed inside cryostats. These vessels are exposed to high pressures and are therefore equipped with safety relief valves and burst discs.

The hydraulic system that operates the vertical positioning system VPS and the horizontal positioning system HPS operates at high pressure, 3000 - 5000 psi. Therefore one should be careful when operating those systems.

The cryogenic system operates at elevated pressure at 4K. One must guard against cold burns and take the normal precautions with pressure vessels when operating this system. Only WBS7 are permitted to install and take out U tubes.

The magnets have a great deal of stored energy as they are large inductors. Always make sure people are clear of them and that the dump resistor is attached to the magnet.

There are several major safety concerns with regards to the detectors, namely 1) flammable gas located in the VDC and FPP, 2) ODH hazard due to CO_2 in the Cerenkov

counter, 3) high voltage due to the photo multipliers on the various detectors and 4) a thin vacuum window separating the detector array from the vacuum system in the spectrometers. The clean agent fire suppression system, while installed to suppress fires, can also be a safety hazard. It is possible for an individual to drop down alongside the box beam to the gantry roof inside the shield house. This area, although technically not a confined space, could conceivably become one in the event that the clean agent system was attached. Personnel should have a 5 minute air pack with them in the event they must enter the area alongside the box beam to the gantry roof inside the shield house.

4.1.2 Hall A Vacuum System

The Hall A vacuum system consists of 5 separate but interconnected subsystems. The largest is designed to supply the Hall A HRS with a self contained 5×10^{-6} Torr vacuum that enables both spectrometers to be pumped down from atm. in a few hours. The target vacuum system is designed to maintain a 1×10^{-6} Torr in order to minimize contamination and provide an insulating vacuum for the cryo target. Rough insulating vacuum for the 4 superconducting magnets is provided by a 360 *cfm* Roots type blower that can be connected to each magnet. The beam line vacuum is maintained by 1 ℓ/s ion pump system used in the accelerator ring and a small turbo pump located near the target. The final subsystem is a differential pumping station located near the target exit port.

Spectrometer Vacuum System

The spectrometer vacuum system is shown in Figure 4.5. Vacuum for the HRS is supplied by an Alcatel 880 ℓ/s Turbo pump backed by a Balzers 360 *cfm* Roots type Blower. This Blower, via a special manifold, also supplies the roughing vacuum to the HRS at the Dipole Inlet Transition. The first Turbo is mounted on the lower side of the Dipole entrance transition. The roughing port is also located on this transition, on the top side. The upper turbo is located on the lower side of the window transition.

Vacuum readouts and interlock outputs are supplied by five (5) HPS series 421 Cold Cathode gauges and seven (7) series 275 Mini-Convectron gauges. In addition to these there will also be a Fisons Micromass 386 RGA head installed in the system for diagnostic purposes. Most of this instrumentation will be located on the Turbo pump manifold (for detailed information see Figure 4.5).

Powered valves, instrumentation and pumps will be controlled and powered at the Vacuum System equipment rack located on each respective spectrometer on the gantry platform. Selective equipment will also be controllable from the Hall A counting house.

Chamber

The HRS vacuum chamber consists of an associated vacuum window, a sieve slit and Q1 transition, Q1 to Q2 transition, Spool section, Dipole transition, Dipole to Q3 transition, and the Q3 to exit window assembly. The spectrometer vacuum is contained by a .007 kapton window at the entrance and a .004 titanium window at the exit.

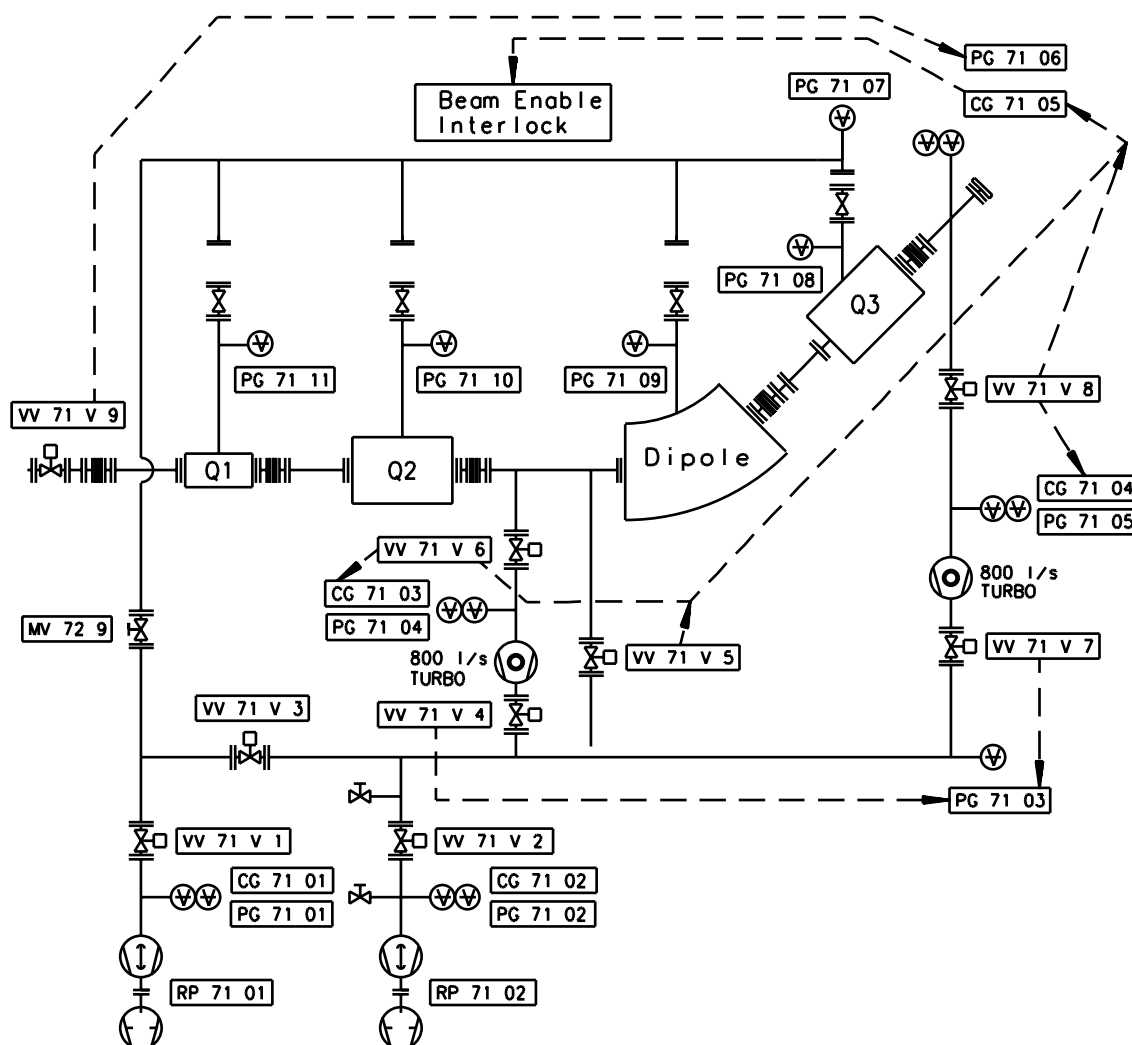


Figure 4.5: HRS vacuum system.

Target Vacuum System

Vacuum for the target chamber is supplied by an Alcatell 880 ℓ/s Turbo pump backed by an Alcatell 21 *cfm* 2 stage vane pump. The Turbo is mounted on the lower ring of the Target Chamber to one side so as not to interfere with the Target Chamber windows.

The same instrumentation is used here as on the spectrometer.

Powered valves, instrumentation and pumps will be controlled and powered at the Vacuum System equipment rack located on the access Balcony. Selective equipment will also be controllable from the Hall A counting house.

Magnet Vacuum System

Vacuum for the magnet insulating vacuum is provided by the Cryo pumping effects of each individual magnet.

All controls for the Magnets are manual as we expect no problem after initial pump down.

The insulating vacuum for each magnet is self contained within the magnet.

Beam Line Vacuum System

Vacuum for the entrance beam line is supplied by 65 ℓ/s Balzers turbo pumps, the first of which is located on the E P chamber, and the second located 3 *m* upstream of the target chamber. Both turbos are equipped with a HPS 7 Series 275 mini Convectron gauge and a HPS series 421 Cold Cathode gauge located near the balcony.

Vacuum readouts and relay outputs for interlocks are supplied by HPS series 421 Cold Cathode gauges. In addition to these there will also be Convectron gauges. Most of this instrumentation will be located on the Turbo pump manifold.

Powered valves, instrumentation and pumps will be controlled and powered at the Vacuum System equipment rack located on the Balcony. Selective equipment will also be monitored from the Hall A counting house. All control is by Accelerator in the MCC.

Beam Exit Vacuum System

Vacuum for the target chamber is supplied by an Alcatell 880 ℓ/s Turbo pump backed by an Alcatell 21 *cfm* 2 stage vane pump which maintains a 1×10^{-4} vacuum on the exit beam pipe.

Between the target chamber and the exit beam pipe there is a .007 *in* kapton window that has a .0375 *in* hole in it at the beam spot. This window acts as a differential pumping station.

Also between the target chamber and the exit beam pipe is an 8 *in* air actuated gate valve that is operated from the MCC.

Vacuum readouts and interlocks outputs are supplied by an HPS 7 Series 275 mini Convectron and an HPS series 421 Cold Cathode gauge which are located near the balcony.

Controls are interlocked to the beam.

The chamber is made of a low mass aluminum corrugated vacuum tube of 1 *m* diameter.

At the exit point of the exit beam pipe is a beam diffuser that consists of 2 .025 *in* beryllium windows with a water filled cavity between them for cooling. The water is circulated through the cavity by a water cooling system located on the Hall floor, and is interlocked through the FSD system with 2 flow switches, one on the supply and one on the return line.

Due to high radiation levels at the exit beam pipe all seals in this area are metal.

Hazards of Vacuum Systems

Hazards associated with the vacuum system are due to rapid decompression in case of a window failure. Loud noise can cause hearing loss. To mitigate the hazard, all personnel in the vicinity of the large chamber with a window are required to wear ear protection when the chamber is under vacuum. Warning signs must be posted at the area.

The scattering chamber is equipped with a large 10 *mil* aluminum window that allows the spectrometers to swing from 12.5° to 165° on the EA and 12.5° to 140° on the HA. In order to protect this window when the Hall is open, lexan window guards are installed.

At the inlet of the sieve slit a Møller 8" diameter 7 *mil* kapton window is provided to separate the target chamber from the spectrometers.

Finally, under the detectors, a 4 *mil* titanium window is provided. Eventually this will be replaced with a low mass mylar/kevlar window.

The 1 ℓ /s vac ion and the cold cathode gauges operate at several KV; consequently there is also a shock hazard.

Additionally, all vacuum vessels and piping are designed as pressure vessels.

4.1.3 The High Resolution Spectrometer (HRS)

The HRS is composed of three superconducting quadrupole magnets, Q1, Q2, and Q3, and one superconducting dipole magnet. The large quadrupoles were manufactured for TJNAF by SIEMENS, the small quadrupole by SACLAY, while the dipole was built for TJNAF by WANG NMR. The quadrupole magnets are referred to as Q1, Q2, and Q3, where a particle first traverses Q1, then Q2 and the dipole magnet and finally traverses Q3.

The magnet system is followed by a large steel and concrete detector hut, in which all detector elements reside. Most of the detector elements have been built by universities involved in the Hall A physics program.

The HRS magnet system is the cornerstone of the Hall A activities. Many of the experiments approved in Hall A center on physics at high resolution and other short-range phenomena, and rely on a spectrometer able to momentum analyze charged particles up to very high momenta. The design value for the maximum momentum accessible to the HRS magnet system is 4 GeV/c.

Magnets and Power Supplies

The HRS magnet's are all superconducting and hence their coils must be maintained at cryogenic temperatures during operations. The LHe required by the magnets is supplied by the End Station Refrigerator, ESR.

All the HRS magnets cryogenic services are supplied through the overhead cryogenic lines. The distribution network begins at the distribution box over the pivot. This box is connected to the rest of the network via the flexible transfer lines over the pivot. The network is adjacent to the upstairs catwalk of the HRS.

Cryogenic information about each magnet is available on the control screens in the counting house, one for each magnet. Normally during run periods the control screens are sent upstairs to the Hall A counting house and information on all the HRS magnets is available on the HRS control screen located in the center of the main console. The control of all magnets is described in a following Subsection.

The power supplies for the magnets are located on the gantry balcony adjacent to the magnets. The supplies are all cooled with LCW.

The front panels of the power supplies are interlocked. Under no circumstances should the front panel of any supply be opened by anyone other than authorized personnel. There is a keyed electrical interlock located in the Hall A counting house main console to prevent the power supplies from being energized at inappropriate times. There are also signs posted listing the dangers of high magnetic fields.

The control interface for the power supplies is available through the HRS control screen in the Hall A counting house.

Personnel

In the event that problems arise during operation of the magnets, qualified personnel should be notified. This includes any prolonged or serious problem with the source of magnet cryogenics (the ESR). On weekends and after hours there will be a designated individual on call for magnet services. Any member of the Hall A engineering group is qualified to deal with unusual magnet situations but in the event of serious problems the technician on call should be contacted.

Quadrupole Magnets

The quadrupoles provide some of the focusing properties of the spectrometer and to a large extent its acceptance. Operating limits imposed on the quads are as follows: 1850A for Q2 and Q3 and 3250A for Q1.

All three quadrupoles for the HRS spectrometer are warm iron superconducting magnets. The soft iron around the superconducting coil enhances the field at the coil center and reduces stray fields. The basic parameters for the first quadrupole, Q1, are an effective length of 0.9 m, useful aperture of 0.3 m and a field gradient of 9.5 T/m. To achieve the lowest possible angle setting of the HRS spectrometer (with respect to the beam line) the incident electron beam passes through a notch in the outer yoke of Q1

when the spectrometer is at its smallest angle of 12.5° . The other two quadrupoles Q2 and Q3, are essentially identical with an effective (magnetic) length of about 1.8 meter, a useful aperture of 0.6 m and a field gradient of 3.5 T/m.

The maximum operating currents (assuming a 4 GeV/c momentum particle) for the quadrupoles are about 3000 A, 1700 A, and 1600 A, for Q1, Q2, and Q3, respectively. This will render pole field values of 1.2, 1.0, and 1.0 T, respectively. The energy stored in the quadrupole fields is sufficient to cause an unrecoverable quench if all the energy stored is dumped into the magnets. Therefore a quench protection circuit is incorporated. However, a quench can only happen if the cryomagnets have a helium level below the coil 60% during operation.

The operating current to the Q1 quadrupole coils is provided by Danfysik System 8000 power supplies, which can operate up to 3500 A current and 5 V. The power supplies will be cooled with a combined maximum water flow of 45 liters per minute.

In addition to the main quadrupole windings, all quadrupoles have multipole windings. To further optimize focusing properties of the HRS magnet system, it was intended to operate including some of these multipole trim coils in order to reduce higher order aberrations. The operating current for these multipole corrections is small, only (the multipole corrections are typically less than 2% of the main quadrupole field), of order 50 A, and will be provided by thirty two Lakeshore power supplies. These power supplies can operate up to 100 A current and 30 V voltage. Since the sextupoles were inadvertently installed rotated 90° from their correct orientation, these trim coils are now considered useless and there are at present no plans to use them.

Cryogenic Procedures

All cryogenics control is handled by WBS7. The cryo control coordinator can be reached at the CHL (x7405) or by calling the MCC.

First Time Startup Check List.

See attached check lists for all quadrupole and dipole magnets (Tables 4.1, 4.2, and 4.3).

Dipole Magnet

The dipole, by virtue of its field index, provides both dispersion and focusing. The present operations envelope states that the supply for the electron dipole may not be operated at a current above 1800 A (4.4 GeV/c). The supply for the hadron dipole may not be operated above 1200 A (3.2 GeV/c).

The dipole for the HRS spectrometer is a superconducting, cryostable magnet. Its basic parameters are an effective length of 6.6 m, a bend radius of 8.4 m, and a gap width of 25 cm. It is configured to achieve a 45 degree bending angle for 4 GeV/c momentum particles at a central field excitation of 1.6 T. For the HRS dipole to reach 1.6 T an operating current of about 1500 A is required.

The dipole has been designed to achieve cryostability up to a field of 2 T, and this property has been extensively tested up to a field of 1.6 T. The cryostable coils are equipped with an energy removal circuit to cover the possibility of an unrecoverable quench. However, this can only happen if the helium level drops below the coil during operation. The current to the coils will be provided by a Dynapower System power supply, which can operate up to 2000 A and 10 V. This power supply is located on the gantry beside the dipole, and will be cooled with a maximum water flow of 35 liters per minute. The flow of the magnet cooling water will be regulated by flow meters installed on the floor of Hall A. The total water flow needed to cool the 4 power supplies for the HRS magnet system (dipole and quadrupoles) amounts to 80 liters per minute, with a supply pressure of cooling water for Hall A of 100 psi.

4.1.4 Operation of the HRS Magnets

Introduction

This is an abbreviated operating manual for the HRS superconducting magnets specifically designed for Hall A experimenters. It provides instructions for setting currents, invoking NMR field regulation and general system monitoring. Curious readers are directed to the references for more in-depth operating instructions and other technical manuals. Copies of the following supporting documents are available in the Hall A Control Room.

References

WANG NMR Dipole	Operation Manual Power Supply
Dynapower	User Manual
Appendix	NMR Tesla meter
Appendix	NMR Field REgulation
Siemens/Fug	Q2/Q3 Power Supply Manual
Saclay/Danfusik	Q1 Powersupply Manual
TOSP	HRS Dipole
TOSP	HRS Quadrupole Q1
TOSP	HRS Quadrupole Q2, Q3
HRS	SC Dipole Magnet Safety Review Vol. 2
HRS	SC Quad Safety Review Vol. 1

Starting Hall A Controls The following is an abbreviated operational manual for the magnets supplied by Javier Gomez.

On hac x-terminal

Account: hacuser

Password: hacuser

Circuit Parameters:

$I_{\max} = 1800 \text{ A}$, $L = 2.52 \text{ H}$, $\tau(\text{slow}) = 420 \text{ s}$, 640 MITS

$R_{\text{dish}} = \text{dump resistor} + \text{cable resistance} = \text{total resistance}$

$R_{\text{total}} = .0045 + .0015 = .006 \Omega$

$R_{\text{dump}} .134 \Omega$, $L = 2.55 \text{ H}$, $\tau(\text{fast}) = 19 \text{ s}$, 29 MITS

Magnet Dipole

Arm (Circle one)-Electron Arm, Hadron Arm

Megger check of coil @ 250 V DC _____

Visual inspection walk through _____

Set water inlet pressure to 100 psi _____

Coil A Trip Voltage (1.2V+) value _____

Coil B Trip Voltage (1.2V-) value _____

Magnet Lead A Trip (1.2V+) _____

Magnet Lead B Trip (70mV) value _____

Magnet Leads are not bipolar and only work in the PS forward polarity.

Magnet lead A must be connected to the PS+

Level Trip (70%) value _____

Magnet Flow A Trip (60 SLPM) value _____

Magnet Flow B Trip (60 SLPM) value _____

Operational Test of trips _____

PS overcurrent trip (2000A) _____

See manual for voltage setting and gain (4V=800A)

Magnet Ready for Operation _____

signature, date

Table 4.1: Hall A Dipole Magnet Check List (15 August 1996)

Circuit Parameters:

$R_{ext} = 0.075 \, \Omega$, $L = 25 \, \text{mH}$, $\tau = 0.3 \, \text{s}$, $V_{threshold} = .1\text{V}$ $I_{max} = 3250\text{A}$

Magnet (Circle one) - Q1, _____

Arm (Circle one) - Electron Arm, Hadron Arm _____

Visual inspection walk through _____

Set water pressure at 100 psi inlet _____

Coil A Trip Voltage + value .25mV _____

Coil B Trip Voltage (-) value .25 mV _____

Magnet Lead A Trip (+) Voltage .80 mV _____

Magnet Lead B Trip (-) Voltage .80 mV _____

Level Trip percent 980%) _____

Magnet Flow A Trip (30 SLPM+) setting _____

Magnet Flow B Trip (30 SLPM-) setting _____

Operational test of trips _____

Magnet Ready for Operation _____

Table 4.2: Hall A Q1 Quadrupole Magnet Check List (15 August 1996)

Circuit Parameters:

$R_{ext} = .125 \, \Omega$, $\tau = 3 \, \text{s}$, Quench $V_{threshold} = .1\text{V}$, $I_{max} = 1850\text{A}$

Magnet (Circle one) - Q2, Q3 _____

Arm (Circle one)-Electron Arm, Hadron Arm _____

Visual inspection walk through _____

Meggelr Magnet @ 250 V DC _____

Set water pressure at 100 psi inlet _____

Coil A Trip Voltage (+) value _____

Coil B Trip Voltage (-) value _____

Magnet Lead A Trip (+) Voltage _____

Magnet Lead B Trip (-) Voltage _____

Magnet Lead Trip (trim) Voltage _____

Level Trip percent (80%) _____

Magnet Flow A Trip (50 SLPM+) setting _____

Magnet Flow B Trip (50 SLPM-) setting _____

Magnet Flow trim Trip (3.6 SLPM) setting _____

Operational test of trips _____

Magnet Ready for Operation _____

Table 4.3: Hall A Q2/Q3 Quadrupole Magnet Check List (15 August 1996)

Type: HAC_xt or HAC_hp (as per instructions when you log-on). A Hall-A Main Control Window pops up, and all subsystem control windows can be accessed via pull down menus from there.

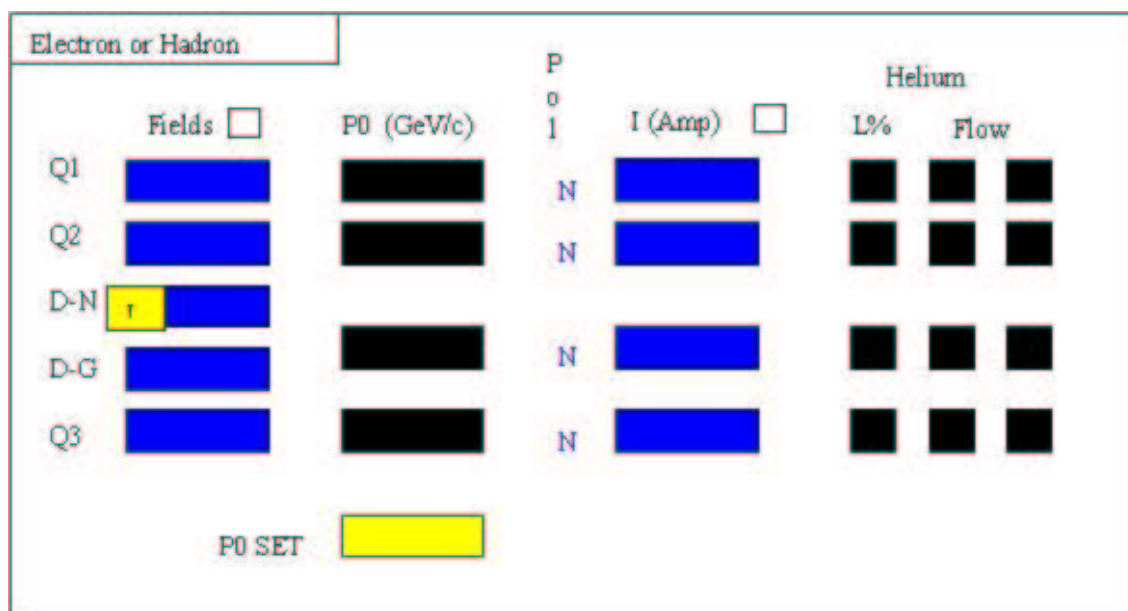


Figure 4.6: Magnet Portion of Main Hall A Control Screen.

4.2 Field Monitoring ^{3 4}

4.2.1 Simple Spectrometer Field Setting (Autopilot Mode)

(All you need when everything is working and power supplies are turned on and ready to go.)

On the Hall A main control screen there is a rectangular box for each spectrometer that looks similar to the illustration (see Figure 4.6).

This box displays a brief summary of the status of the spectrometer magnets and their cryogenic systems. The blue fields (with white numbers) give readbacks of the magnetic fields and currents in each magnet. The black fields also give readbacks, however in this case if the text appears green those parameters are OK while if they are red then that parameter is out of tolerance and may indicate a fault condition. For example if the helium level goes below a certain point the magnet will be automatically turned off. In some cases it may be desirable to monitor certain critical quantities on a strip chart (e.g. Magnet settings). A strip chart tool is available for this purpose from the bottom of the main control screen.

To set the spectrometers for a given value of central momentum (P0) type the desired P0 value into the yellow P0 SET box and hit return. The magnets will be automatically set to the correct values. All green numbers in the P0 column indicates that the desired field or current settings have been reached. **Caution:** Re dipoles, in general

³ CVS revision Id: nmr-1999.tex,v 1.1 2003/06/06 15:44:08 gen Exp

⁴Authors: J.LeRose <mailto:lerose@jlab.org>

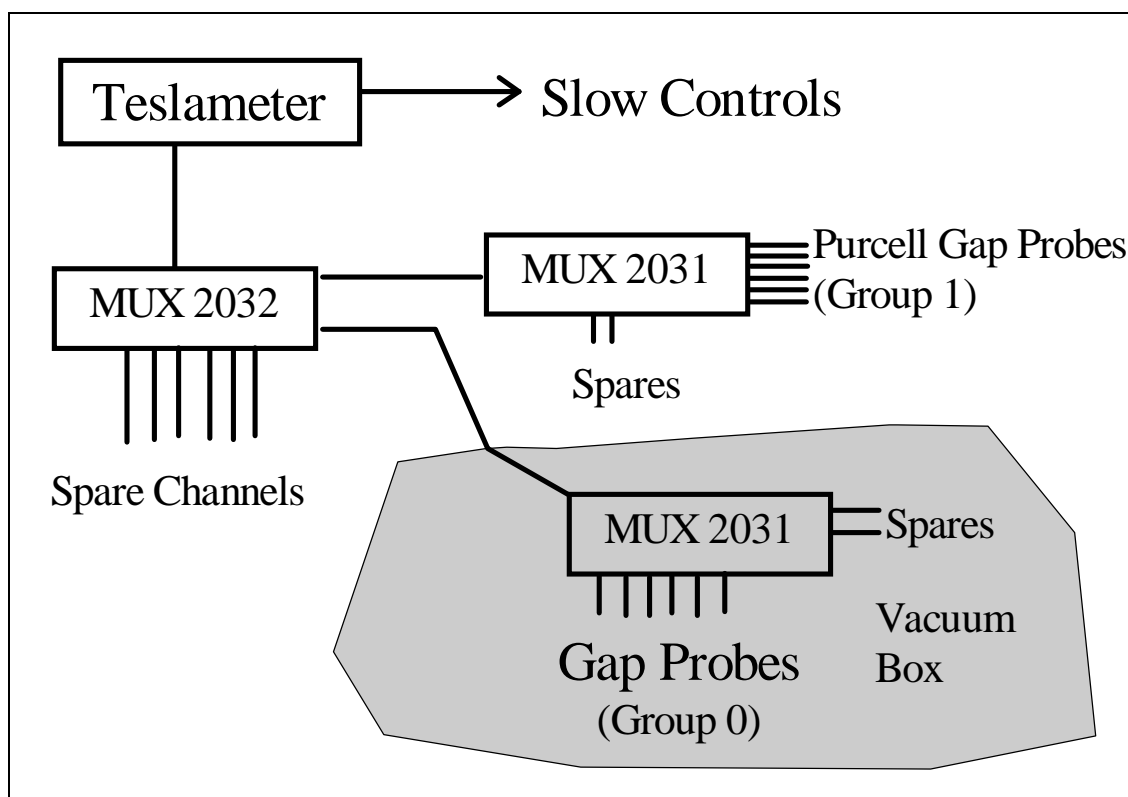


Figure 4.7: Basic layout of NMR system

it's a bad idea to assume that at the first instant that the P0 display turns green that the desired field has been reached and you can start taking data. Stable field is in general not achieved for from 15 to 30 minutes after reaching the nominal desired field. This settling time depends on the magnet (Hadron is slower than Electron) and the magnitude of the field change (small changes settle faster than big changes). Experimenters are advised to observe both the field reading and current reading on the magnet in question and verify that things are stable to their satisfaction before proceeding.

4.2.2 Dipole Field Monitoring Electron Arm

(see special instructions for running the Hadron Dipole in field regulation mode)

Basic Setup

Each spectrometer dipole magnet is equipped with a Metrolab PT 4025 NMR Teslameter, several field probes, and multiplexers (to allow switching between the probes). Details of the operation and theory of operation for the Teslameter can be found in its user manual, a copy of which is available in the the counting house. The basic layout is shown in Figure 4.7

The "Gap Probes" (Group 0 in the controls) are located in two groups of three; one

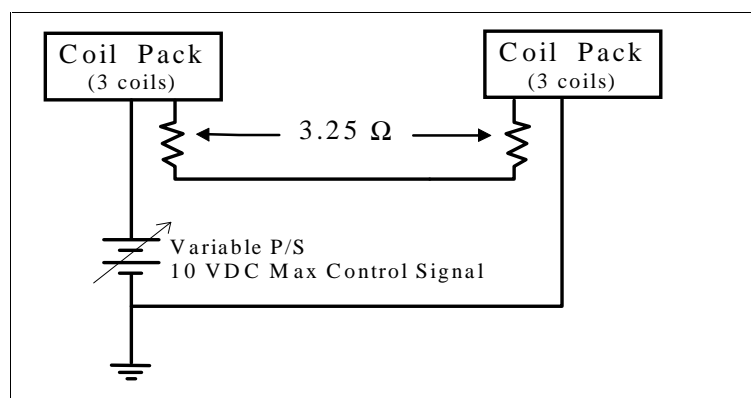


Figure 4.8: Gradient Compensating Circuit.

Table 4.4: Dipole NMR probe field ranges

Probe Type	Field Range (T)
3	0.17 - 0.52
4	0.35 - 1.05
5	0.70 - 2.10

group on the low field side of the gap and the other on the high field side of the gap. The groups of three are made up of one each of the manufacturer's type 3, 4 & 5 probes, designed to cover different field ranges (see Table 1). The six "Purcell Gap Probes" (Group 1 in the controls) are located in the Purcell gap of the magnet and consists of two each of the above types. *Note: Since the fall of 1998 the multiplexer-multiplexer in the electron arm, MUX 2032, has been bypassed and hence the "Purcell Gap Probes" are currently unavailable. There are no plans to fix this multiplexer in the immediate future.*

The "Gap Probes" are equipped with coils which provide a field gradient that cancels out the field gradient of the magnet in the vicinity of the probe. These gradient compensating coils are part of a simple circuit that is completely independent of the Teslameter. The basic circuit for the compensating coils is shown in Figure 4.8

The following graphs (see Figures 4.9, and 4.10) can be used to determine optimum values for the compensating coil control voltage. It should be noted that the setting of the compensating coil current is not very critical in most cases. In general if you're within 10% of the correct value everything should work fine.

4.2.3 Authorized Personnel

The following individuals are responsible for NMR operation problems.

J. Gomez - x7498

J. LeRose -x7624

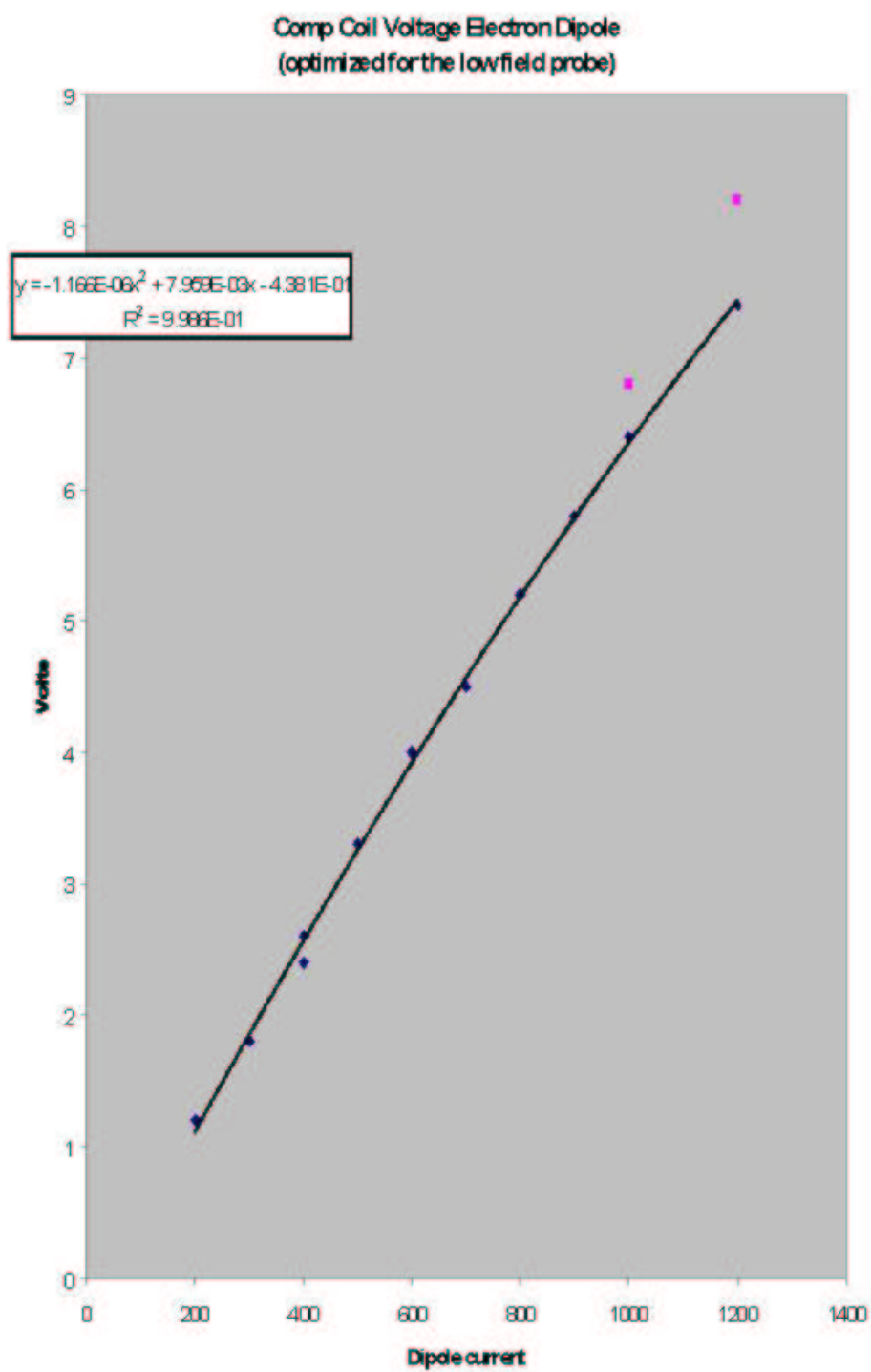


Figure 4.9: Control Voltage calibration for Electron Dipole.

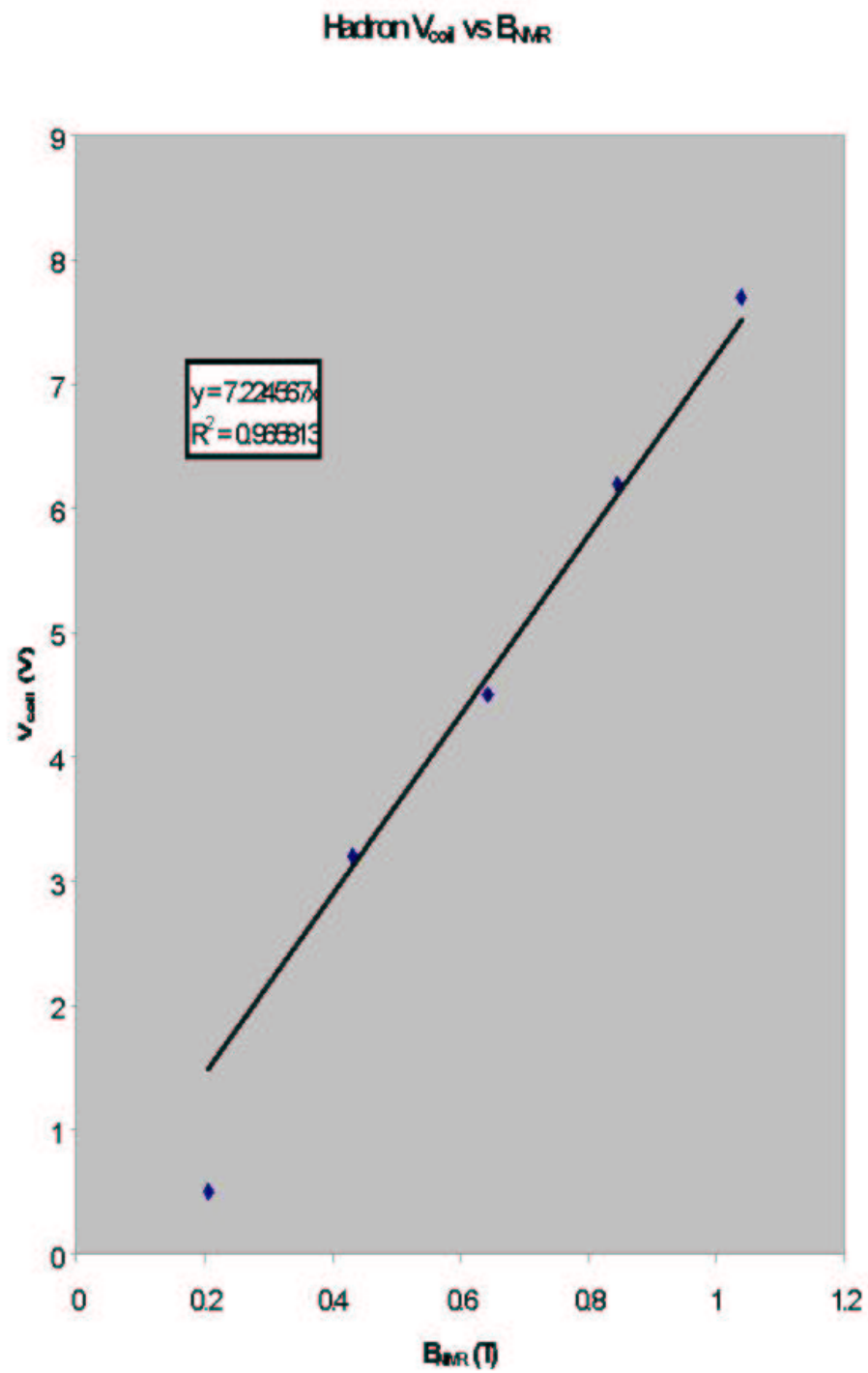


Figure 4.10: Control Voltage calibration for Hadron Dipole.

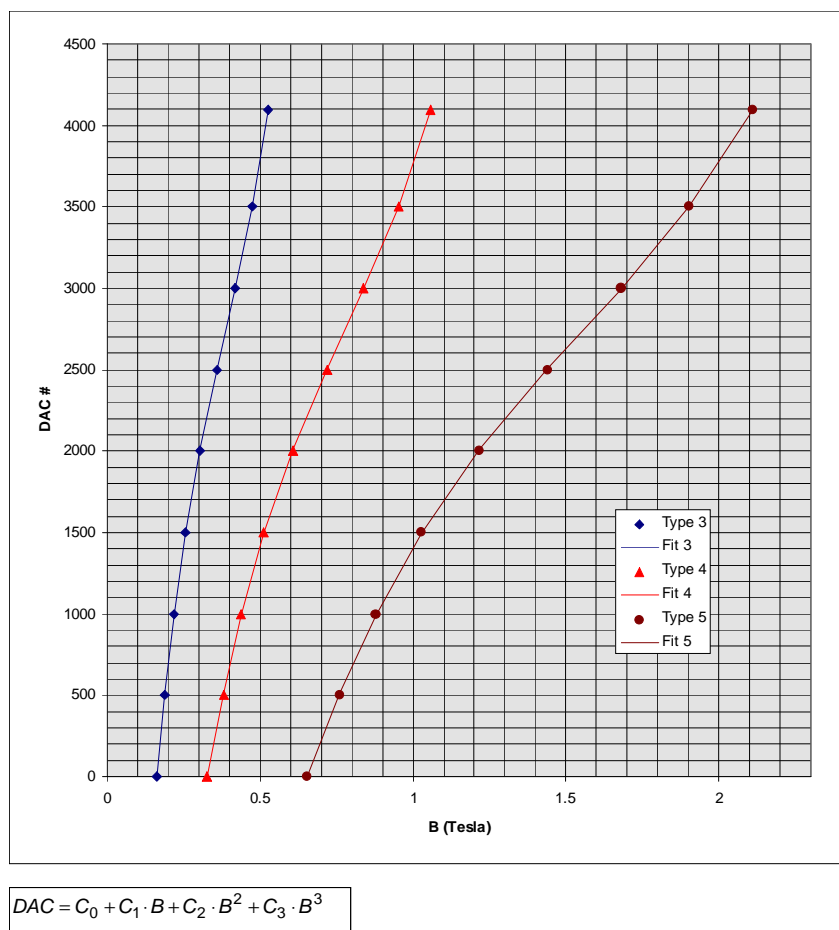


Figure 4.11: DAC Calibration for manual operation of NMR probes.

4.2.4 NMR Operating Procedure:

When running in Autopilot mode (see: Simple Spectrometer Field Setting) the compensating coil voltage is set automatically and the probe appropriate for the field desired is selected. The gaussmeter is placed in SEARCH Mode and the dipole power supply regulator is turned on. In this case the dipole current is adjusted to achieve the desired field. If the NMR gaussmeter is not "locked" a backup Hall Probe is used until the NMR "locks". The user should just stand back and let it work. What follows are instructions for using the NMR gaussmeter in situations where Autopilot doesn't work or some special supplemental measurements are required.

In principle it is possible to make the field measurements using the SEARCH mode in the Teslameter. In this mode you select a probe and the meter explores the whole field range of the probe until it finds and "locks" on the resonant signal indicating that it has a field measurement. A "lock" is indicated on the controls display by positive field values. This has the advantage of simplicity but in practice can be time consuming and doesn't always work. The problem being, in situations where there is a lot of noise mixed in with the signal, the circuitry has problems distinguishing the signal from the noise and gets lost before it ever finds a lock. The problem is exacerbated when the field being measured is at the high end of the probe's range. In this case the search starts at the low end and keeps getting hung up on the noise and never gets to the field range of interest. The solution to this problem is to tell the device approximately what field it's looking for and use the AUTO mode to find the lock. In the procedure below that is what we will be doing.

In any case, for "gap probes" (group 0) you must energize and adjust the gradient compensating coils for the field ranges to be measured before trying to make measurement.

For studies involving 10% changes in the field settings the compensating coil current can be set once and left alone.

Recommended Procedure:(turn the **REGULATOR OFF** for all non-autopilot field measurements)

For group 0 probes set compensating coils appropriately (see figures).

Put meter in MANUAL mode with SEARCH OFF

Select a probe and polarity (**Group 0: Probes 0, 1, 2 negative; Probes 3, 4, 5 positive**)

Type in DAC number for the field range being measured (see below)

Select AUTO and wait for a lock (positive field reading)

Verify that you have a good lock by checking the oscilloscope for a clear resonant signal.

Go back to 2. for the next probe

If you have problems see the table listing problems and possible solutions.

Selecting DAC #'s

In selecting the DAC # to use for the field of interest use either the graph in Figure 4.11 or the polynomial below that.

Problems and Solutions

Symptom	Diagnosis and Cure
Weird numbers on displays, controls for all magnets fouled up	Need to reboot. See instructions below.
NMR Teslameter does not respond to commands and display shows all zeros.	Meter's communications are somehow hung up. Push RESET .
Will not lock Still will not lock	Very high noise level makes resonance hard to find. Very high noise level makes resonance hard to find. Search for the resonance manually by adjusting the DAC in manual mode until you see the resonant signal. (It helps if you know what field you expect so you'll know where to look).
You find resonance manually but still can't get a lock	Check probe polarity. Try decreasing and increasing DAC number by 1. Optimize signal by adjusting compensating coils.
Can't find resonance manually	Try a different probe. Use readings from other probes to tell you where to look for the resonance with the probe that's giving you trouble. Make sure compensating coils are energized properly. Make sure magnet is on.

Hadron Dipole Field Setting Instructions: Turn on power supply (contact Mark Stevens, John LeRose, or Javier Gomez for assistance).

Turn on field regulation mode. Type desired field value into FieldSet (yellow field). Wait for field to reach the desired value (read from the blue field). After reaching the desired field wait 15 minutes to assure stable field. Pay attention to the current and field readings. **If** the NMR is locked, (the NMR is locked if the field reading in the blue field has a positive number and is updating itself), don't worry it will get there.

If the NMR is not locked (negative but updating number in the blue field) **but** the

current appears to be going in the right direction, don't worry it will get there and the NMR should lock when you get into the vicinity of the desired field. If you're worried anyway and want to watch the field change, push SEARCH. (The NMR will search over the full range of the probe rather than just in the vicinity of the desired field.) The NMR should lock in a minute or two.

If the NMR is not locked **and** the current is going in the wrong direction (This can happen if you ask for a new field before you reach a stable setting), you **must** push SEARCH. (The NMR will search over the full range of the probe rather than just in the vicinity of the desired field.) The NMR should lock in a minute or two and the software will correct the current setting appropriately but slowly. If the NMR doesn't lock you may have to ask for a field value appropriate for the present current ($\sim 1.1 \times 10^{-3}$ T/Amp). The NMR will only search in the limited region of the requested field and should find a lock more easily. After getting the lock let things settle in for a few minutes and then ask for the field you want again. In extreme cases you may have to nurse it through the transition by asking for multiple small increments. If you ask for a change of less than 5% the NMR should not lose its lock.

To shut down: Set FieldSet to .18. Let current run down to just over 100 Amps. Then push stop on Dipole control screen

Problems	Explanation	Action
NMR not locked but current is changing in the right direction	Normal operation for large field changes	Wait. (see above)
NMR locked but current going in the wrong direction.	Normal operation.	Wait.
NMR locked but field not correct and current not changing	Field regulation is disabled or software is confused.	Check that field regulation is enabled. Enter desired field value or one very near the desired value again.
NMR field display freezes. (Usually but not always shows -#.0000000)	NMR Gaussmeter is not communicating with software.	Push RESET .

Table 4.5: NMR troubleshhoting

4.2.5 Powering Up Dipole Magnets:

Use these instructions to recover from loss of a magnet due to a fault (e.g. He level or lead flow fault). The order of actions matters.

(Contact Tech on call if anything behaves funny or things don't respond as expected. Sometimes after a trip an access to the Hall is required to reset things)

1. Wait for Iout=0 (you can't and don't want to do anything while the magnet is in emergency fast dump mode.)
2. While waiting, make a log entry re the fault. Give details such as time, coincident activities, and nature of the fault.
3. Make sure the fault is cleared. (e.g. He level and flow rates returned to normal values and stable)

4. In the HRS Hadron (Electron) Dipole Systems' control panel:

- a) Press RESET (verify that all faults are cleared in the middle column)
- b) Press START (Display will indicate Power Supply ON and magnet ENGAGED)

Power supply and magnet are ready to go. From here you can return to "Autopilot Mode" (type in desired P0 on control screen and wait) or proceed as described below. For Electron dipole type in desired current in I Set and the power supply will respond. For Hadron dipole go to HRS HADRON DIPOLE NMR control panel.

1. Press RESET
2. Press Reg. Enable YES
3. Press Search ON (should already be on but it doesn't hurt to check)
4. Type desired field into Field Set (T) field.
5. Wait for field to reach the desired value. (In general it's a good idea to wait about 15 minutes after first reaching the desired field before taking data.) See Hadron Dipole Field Setting for more details and help with trouble shooting.

4.2.6 Starting Q1 Power Supply:

Do this when a fault causes the power supply to shut off.

Wait for fault to clear (watch He levels).

1. Push RESET (check all faults cleared)
2. Select desired polarity
3. Push ON
4. Type in ISET (yellow field) or re-enter P0 in Autopilot Mode).

4.2.7 Starting Q2/3 Power Supply:

Do this when a fault causes the power supply to shut off.

1. Wait for cause of fault to clear (e.g. low Helium level)
2. Press RESET
3. Select polarity

4. Press ON
5. Type in ISET (yellow field) or re-enter P0 in Autopilot Mode.

4.3 Collimators and Sieve Slits ^{5 6}

Both spectrometers have front-end devices for calibrating the optical properties of the spectrometers. These are known as the collimator boxes. These boxes are positioned between the scattering chamber and the first quadrupoles (Q1). Each box is carefully aligned and rigidly attached to the entrance flange of the Q1 of the respective spectrometer. The boxes are part of the vacuum system of the spectrometer.

Inside each box a ladder is mounted which is guided by a linear bearing and moved up and down by a ball screw. On this ladder 3 positions are available to insert collimators. Below this ladder a special valve is mounted that can isolate the vacuum in the spectrometer from the target system. This valve should be activated when it is moved in front of the holes connecting the box with spectrometer and target chamber. A schematic view of the collimator box is shown in Figure 4.12.

Vacuum requirement is 10^{-6} Torr. The material for the box is aluminum. It is possible to open one side of the box so that collimators can be exchanged. The reproducibility of collimator positions after moving the ladder and/or after replacing a collimator is better than 0.1 mm in horizontal and vertical direction. The dimensions of the box are roughly height=175 cm, width=35 cm and depth=15 cm. The tolerance in the dimension of the 7 msr collimator hole is ± 0.5 mm in each direction. The tolerance in the position of each of the sieve-slit holes is ± 0.1 mm in each direction.

A typical sieve slit collimator is shown in figure 4.13. It consists of a plate of roughly 14 cm x 20 cm containing 49 holes positioned in a regular 7x7 pattern. This slit is made out of 5 mm thick tungsten. The holes have a diameter of 2 mm except for the central one and one positioned off-diagonal which have a diameter of 4 mm. The horizontal distance between the holes is 12.5 mm while the vertical distance is 25.0 mm.

To get the latest information on the dimensions and locations of the collimators see the Hall A homepage on the web⁷.

4.3.1 Authorized Personnel

E. Folts - x7857 (mechanical and vacuum systems).

J. Gomez - x7498 (computer controls and electrical systems).

4.3.2 Safety Assessment

The collimator boxes form part of the vacuum system for each spectrometer. All hazards identified in section spectrometer vacuum section applies to the collimator box as well.

In addition, safe access to the top of the collimator boxes is needed during manual operation of the box as outlined below. Due to the proximity of the collimator boxes

⁵ CVS revision Id: slit.tex,v 1.3 2003/06/06 16:13:37 gen Exp

⁶ Authors: J.LeRose <mailto:lerose@jlab.org>

⁷<http://hallaweb.jlab.org/>

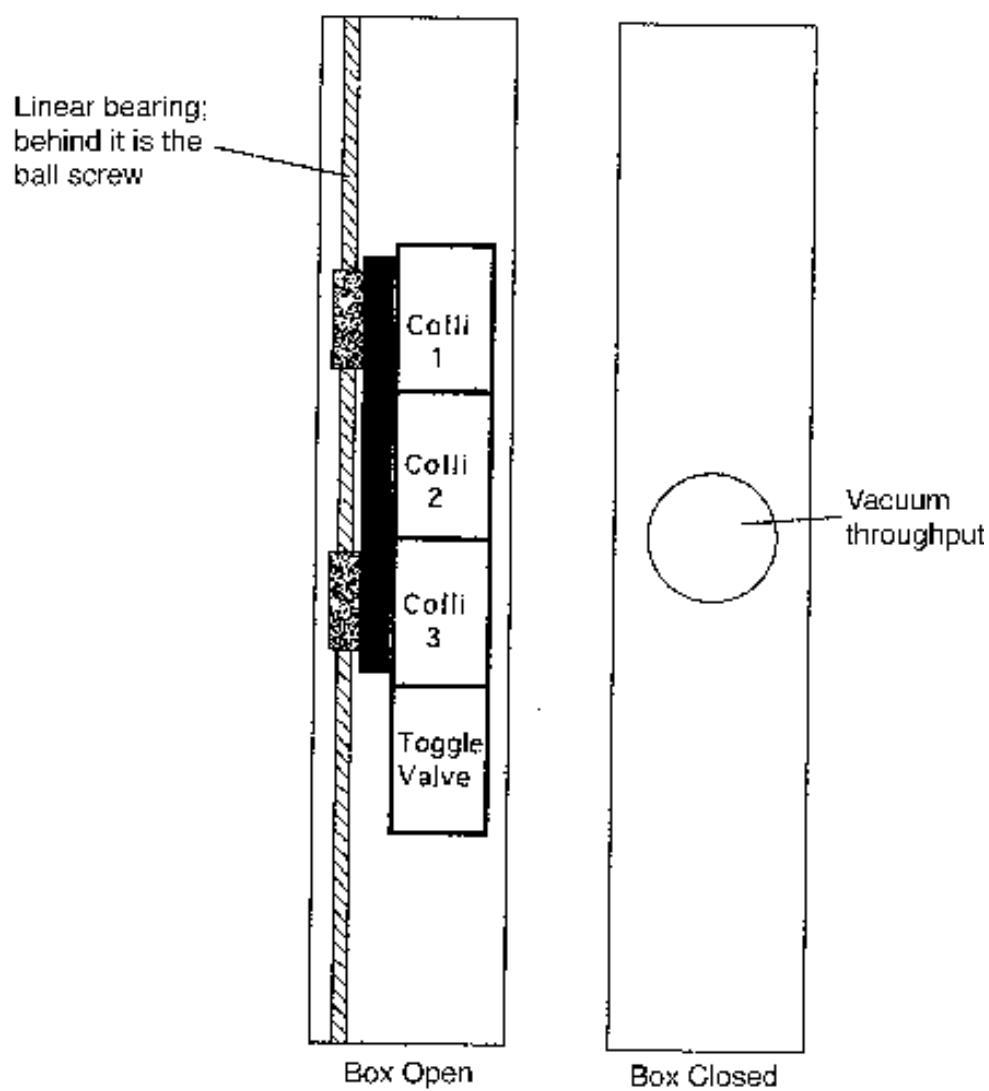


Figure 4.12: Schematic layout of the collimator box.

Sieve Slit

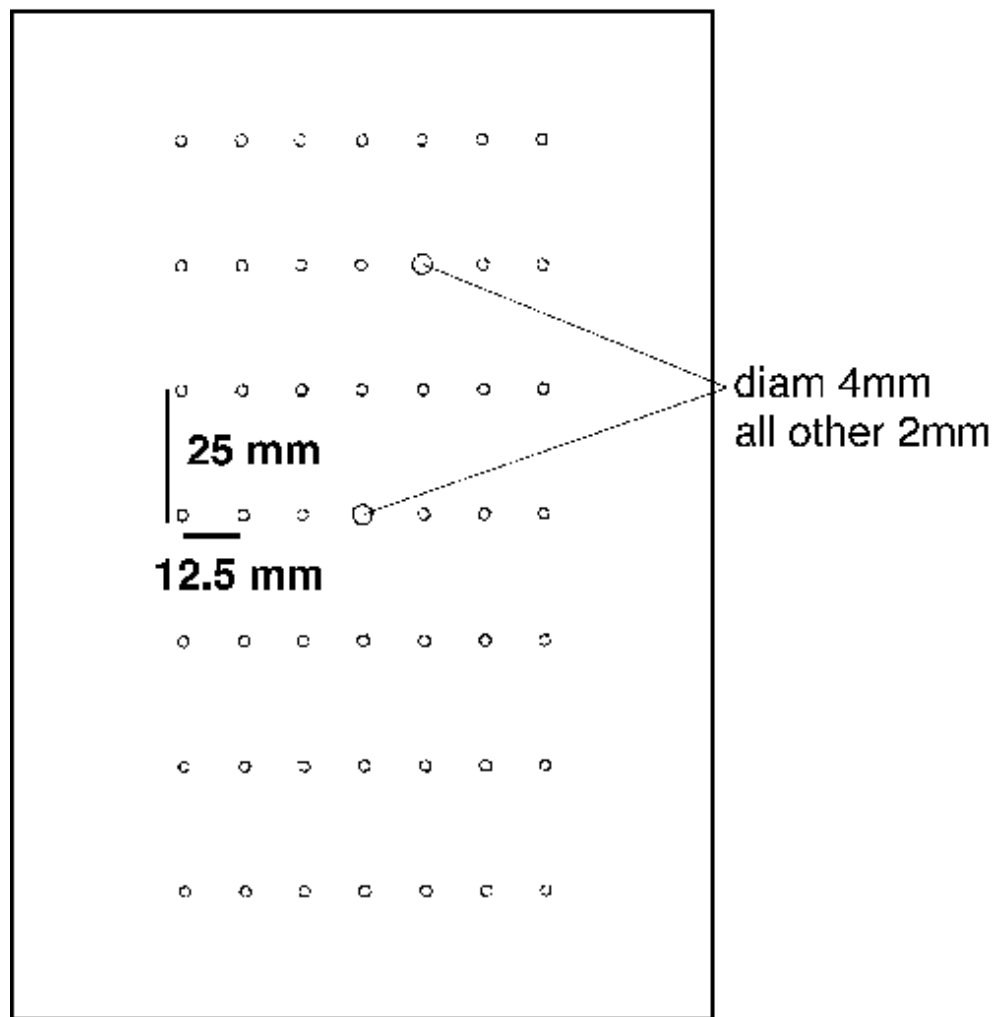


Figure 4.13: Sieve slit collimator for optics calibration.

to the scattering chamber, and Q1 quadrupoles, all necessary safety precautions with regards to vacuum windows, electrical power cables, cryogenic transfer lines, and high magnetic field should be taken.

4.3.3 Operating Procedure

Slit position is changed remotely from the standard Hall A control screen.

4.4 Spectrometer Alignment ^{8 9}

At present, the systems implemented to determine the alignment of each spectrometer (roll, vertical angle/pointing and horizontal angle/pointing) without the help of the Accelerator Division Survey group are limited to roll, vertical angle and horizontal angle.

A bi-axial inclinometer is used to determine the roll and vertical angle (also known as pitch) of each spectrometer. These inclinometers are attached to the back of the dipoles at the power supply platform level. The inclinometer measurements are displayed in the main Hall A controls screen (alignment mosaic). Agreement between the inclinometer readings and survey measurements are better than ± 0.1 mrad over all presently available history.

The horizontal spectrometer angle is determined from floor marks set in place by the survey group. Floor marks have been placed every 0.5° covering the useful range of both spectrometers. The marks are located at a distance of ~ 10 m from the target center. A ruler attached to each spectrometer dipole runs over the floor marks and it acts as a vernier to interpolate between marks. The location of a given floor mark on the ruler can be viewed from the Hall A Counting House through a TV camera. The camera is able to move along the length of the ruler so that any parallax effect can be eliminated. The camera motion is controlled from the main Hall A controls screen (alignment mosaic) through two push buttons. Two fields on the same mosaic (Flr Mrk/Vernier) allow one to input the values read from the TV monitor. The effective spectrometer angle is then calculated and displayed on the same mosaic. A terminal based program (setspec) is available on the controls computer “hac” which, for a given angle, returns the floor mark value and its location on the ruler to which the spectrometer should be set to obtain the desired angle. Spectrometer horizontal angle surveys and floor mark determinations agree to ± 0.2 mrad.

4.4.1 Personnel Responsible

J. Gomez (pager: 849-7498).

⁸ CVS revision Id: AlignmentOps.tex,v 1.4 2003/06/06 16:15:32 gen Exp

⁹ Authors: J.Gomez <mailto:gomez@jlab.org>

Chapter 5

HRS Detectors

5.1 Overview ^{1 2}

The detector package of each spectrometer has trigger, tracking, and particle ID components. In addition, the Hadron spectrometer has a unique proton polarimeter. Particles which have passed through the magnetic elements first encounter the tracking detectors to minimize the multiple scattering contribution to the angular and energy resolutions of the spectrometer. The tracking part consists of two identical vertical drift chambers. The trigger detectors include two planes of thin plastic scintillator counters, gas and aerogel Cerenkov counters and a shower counter. On the hadron spectrometer the shower counter or large scintillator counter can be used in the trigger. Particle ID is provided by several techniques. For electron identification the electron arm, EA, has the gas Cerenkov counter and two layers of a segmented lead glass shower counter. Because the hadron arm, HA, also can be used for experiments with electrons it is equipped with a short version of the gas Cerenkov counter and one layer of a segmented lead glass shower counter. Pion identification in both spectrometers relies on an aerogel Cerenkov counters which presently have aerogel radiator with a refraction index, n , of 1.025. Aerogel Cerenkov counter commissioning is not yet completed. For particle momenta below 800 MeV/c, the dE/E in the scintillator and shower counters can be used for separation of pions and protons. The large distance between planes of the trigger scintillator counters (2 -3 m) allows a direct measurement of the particle speed with resolution (σ) of 0.07. Measurement of the time of flight on the long path from the target to the spectrometer (25 m) provides another powerful particle ID for coincidence experiments. The focal plane polarimeter on the HA operates with proton momenta up to 3 GeV/c with a figure of merit 0.03.

The detector packages are installed inside of the Shielding Huts (SH). Access to the Shielding Huts is via very heavy swinging front doors. The main structure of the SH is made from 3 *in* thick steel plates. The side walls and bottom surfaces of the SH are

¹ CVS revision Id: overview.tex,v 1.3 2003/06/06 17:00:27 gen Exp

²Authors: Dr.No <mailto:????@jlab.org>

covered inside with 1 *in* thick lead slabs. Outside of the steel box, concrete is used for neutron protection. The front door has about 34 *in* of concrete and 3 *in* of lead. Side walls are covered with 17 *in* of concrete. The roof of the SH has 10 *in* of concrete above 3 *in* of steel. The lower half of the side walls facing the beam dump have an additional cover of 15 *in* of concrete. Additional “Line of Sight Shielding”, LSS, is installed at a distance of 5*m* from the target. This consists of 2 to 3 *m* of concrete. High energy pions interact in this concrete before decaying. The LSS reduces the rate of high energy muons, which are produced in pion decay. The overall result from SH and LSS is a reduction factor of 10 to 20 in the counting rate of a single scintillator counter (according to calculations).

The 2 VDCs provide accurate tracking information. They are mounted on a movable frame which slides along Thompson rails to hard stops. The position of the VDC on the frame and location of the Thompson rails is surveyed relative to the Hall center. The rest of the detectors are mounted on a detector frame which can be moved out of the Shielding Hut for detector maintenance.

5.1.1 Geometry of the Spectrometer Detector Packages

Tables 5.1 and 5.2 give geometry information for the electron arm and hadron arm detector packages. The values in the tables indicate the position of the central point of the detector. The origin of coordinate system (0,0,0) is located at the intersection of the mid plane of the spectrometer and the nominal focal plane (\sim middle of the Bottom VDC).

detector	location actual	location IDEAS model	width X	width Y	BEAM X(+)	X(−)	ENVELOPE Y
VDC1*	0		1942	271	843	- 824	+/- 57
VDC2*	572		1942	271	932	- 911	+/- 85
S1	1311	1321	1718	356	696	-1022	+/- 163
AERO	1646		199	414	709	- 888	+/- 182
GAS	2535		2200	650	886	-1110	+/- 279
S2	3358	3378	2197	540	897	-1124	+/- 285
preSHOW	3502	3546	2400	700	925	-1158	+/- 301
SHOW2	3780	3912	2400	900	964	-1207	+/- 322

Table 5.1: Locations of the detectors on Electron Arm in mm.

detector	location actual	location IDEAS model	width X	width Y	BEAM X(+)	X(-)	ENVELOPE Y
VDC1*		0	1942	271	843	- 824	+/- 57
VDC2*		500	1942	271	932	- 911	+/- 85
S1		1287	1760	360	675	- 845	+/- 163
AERO		1617	1872	414	709	- 888	+/- 182
SC1		1837	1780	480	738	- 924	+/- 198
GAS		2409	2200	650	857	-1073	+/- 263
SC2		2952	2080	640	865	-1083	+/- 268
S2		3141	2220	640	877	-1099	+/- 274
Analyzer		3495	2190	680	916	-1147	+/- 296
SC3		3907	2540	1000	1099	-1343	+/- 457
SC4		4264	3170	1500	1382	-1645	+/- 705
S3		4477	3600	1550	1437	-1704	+/- 752

Table 5.2: Locations of the detectors on Hadron Arm in mm.

5.2 Vertical Drift Chambers ^{3 4}

5.2.1 Overview

The High Resolution Spectrometer Vertical Drift Chambers provide a precise ($\pm 125 \mu\text{m}$) measurement of the position and angle of incidence of both recoil electrons (in the HRSe) and knockout protons (in the HRSh) at the respective spectrometer focal planes. This information may be combined with the knowledge of the spectrometer optics to determine the position and angle of the particles in the target.

Each Hall A spectrometer boasts its own VDC detector package. These packages are located on permanent rails mounted on the spectrometer decks in the shielding huts above the outrun windows but beneath the space frames. The packages consist of two VDCs, and are identical in all aspects. The VDCs have been constructed without guard wires. Each VDC is composed of two wire planes in a standard UV configuration - the wires of each plane are oriented at 90° to one another, and each plane is oriented at 45° with respect to the nominal particle trajectories (see Figures 5.1, 5.2).

Operation of the VDCs requires the application of both High Voltage (HV) across the chambers themselves and Low Voltage (LV) across the preamp/disc cards, which are mounted on the sides of the VDCs, within the confines of the protective aluminum Faraday cage. The chamber gas is a combination of argon (Ar) and flammable ethane (C_2H_6) which is bubbled through alcohol. Gas is routed from bottles located in the Hall A gas supply shed to gas supply control panels located on the main level of the space

³ CVS revision Id: vdc.tex,v 1.3 2003/06/06 17:00:27 gen Exp

⁴ Authors: J.Segal <mailto:segal@jlab.org>

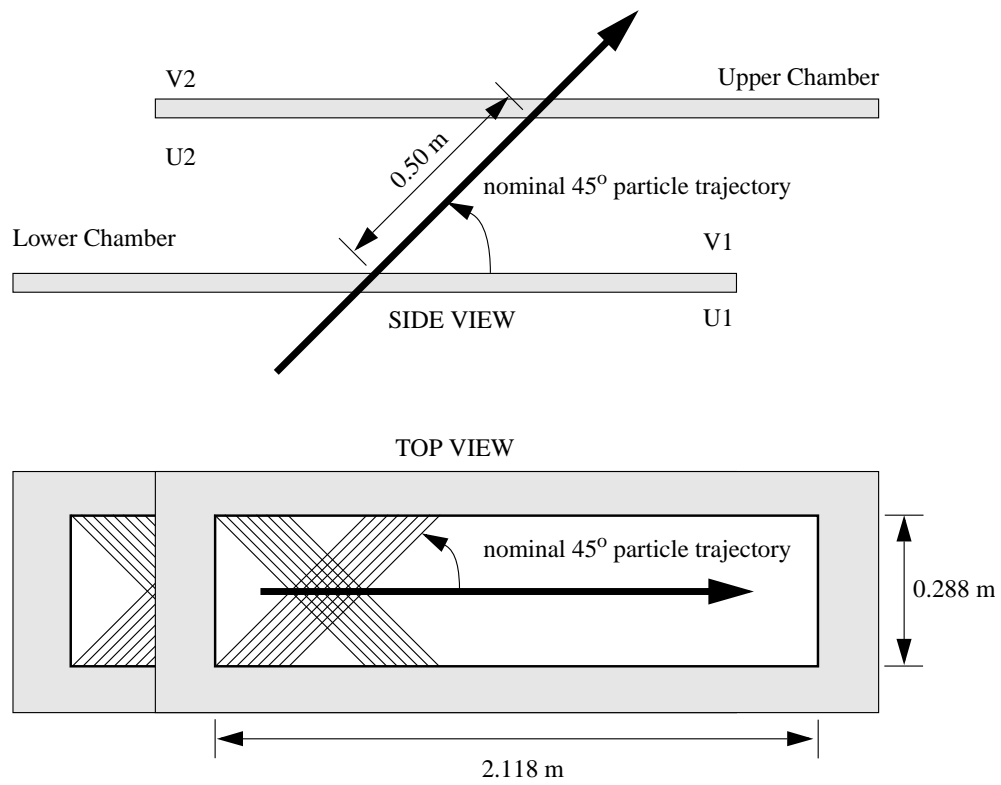


Figure 5.1: Relative VDC geometry

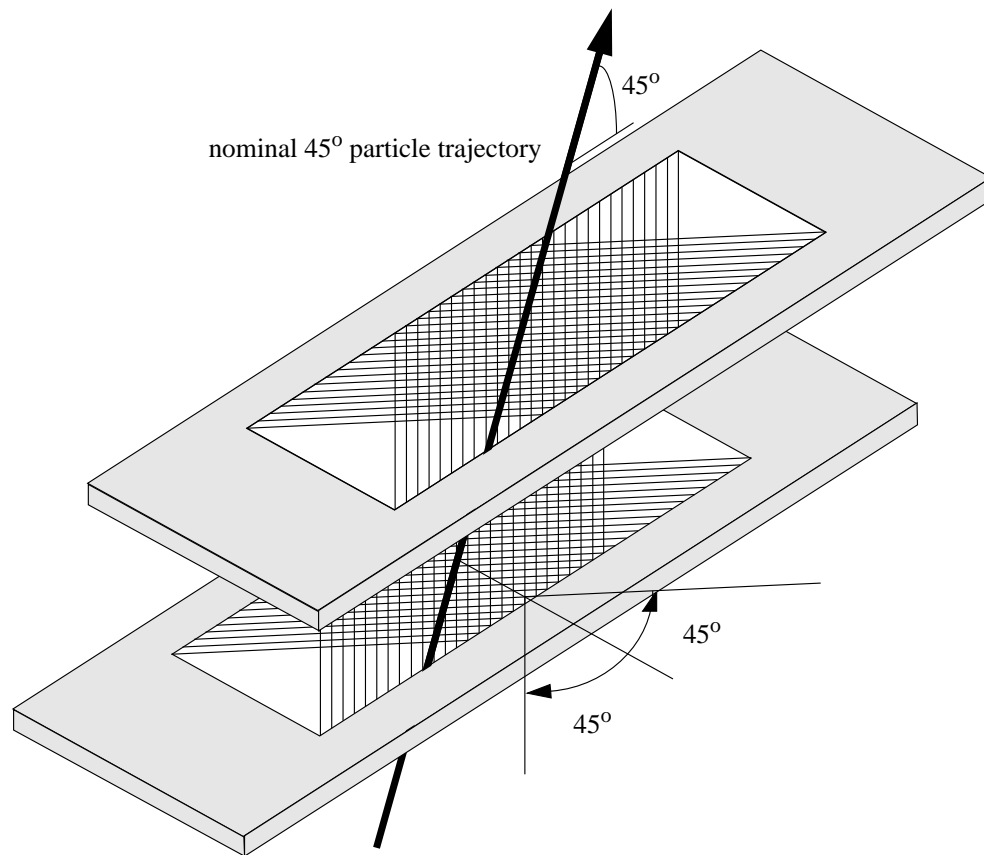


Figure 5.2: Relative VDC geometry

frames in the detector huts.

As charged particles pass through the chamber gas in the VDCs, they produce ionization. This ionization drifts along the electric field lines defined by the high voltage planes and the signal wires. Ionization is collected in the form of analog pulses on the signal wires. The pulses are then amplified, discriminated and used to start multihit TDCs, which are subsequently stopped by the overall event trigger. The TDCs are read out by the CODA acquisition software. The data are histogrammed online by the DHIST software. In-depth offline data analysis requires the ESPACE software.

5.2.2 Operating Procedure

Gas Flow Operating Procedures Chamber gas is delivered to a given VDC detector package via HAGS, the Hall A Gas System. Complete details of this system are presented elsewhere in this manual.

Each VDC detector package consists of two VDCs connected in parallel (see Figure 5.3). All gas connections are made using PolyfloTM tubing and Jefferson Lab specified connectors. Gas enters the chamber assembly after bypassing an overpressure bubbler containing 15 mm of (edible) mineral oil. Gas is exhausted from the VDC package through a second bubbler containing 5 mm of mineral oil. Each chamber has a volume of approximately 30 ℓ and is operated slightly above atmospheric pressure. Standard flow rate set points are clearly labeled next to the control panel flow meters. The gas flow through the chambers may be independently varied and is typically set to 7 ℓ /hr. A typical chamber leakage rate measured against the 5-mm mineral oil load is ≤ 3 ℓ /hr. The flow rate of 7 ℓ /hr when combined with the leak rate of ≤ 3 ℓ /hr ensures a complete exchange of gas in the chambers roughly every 8 hours. When a bottle is nearly empty (say 90%), it should be changed since the quality of the gas at the bottom tends to be low. Gas bottles may only be changed by authorized personnel.

The status of the gas handling system should be monitored carefully every shift. Manual logging is not required as the system status is constantly logged via EPICS. Any substantial deviation from the median parameters can result in a change in the operational parameters of the VDCs and should be immediately investigated. If at all possible, gas flow should be continuously maintained, even in no-beam time periods. This avoids time loss to reconditioning and maintains the desirable steady-state operating condition. Further, it is critical that gas flow has been maintained for 24 hours prior to any power up.

Power Supplies and Electronics Procedures The power supplies and readout electronics associated with the HRS VDCs are all commercially designed. The reader is directed towards the manuals made available by the manufacturer for the detailed information not provided here.

A Bertan 377N HV power supply, modified to allow a remote reset, provides -4.00 kV nominal to each of three HV planes in a given VDC detector package via a 10 M Ω Hammond splitter box (see Figure 5.4). The power supply is located in the detector hut

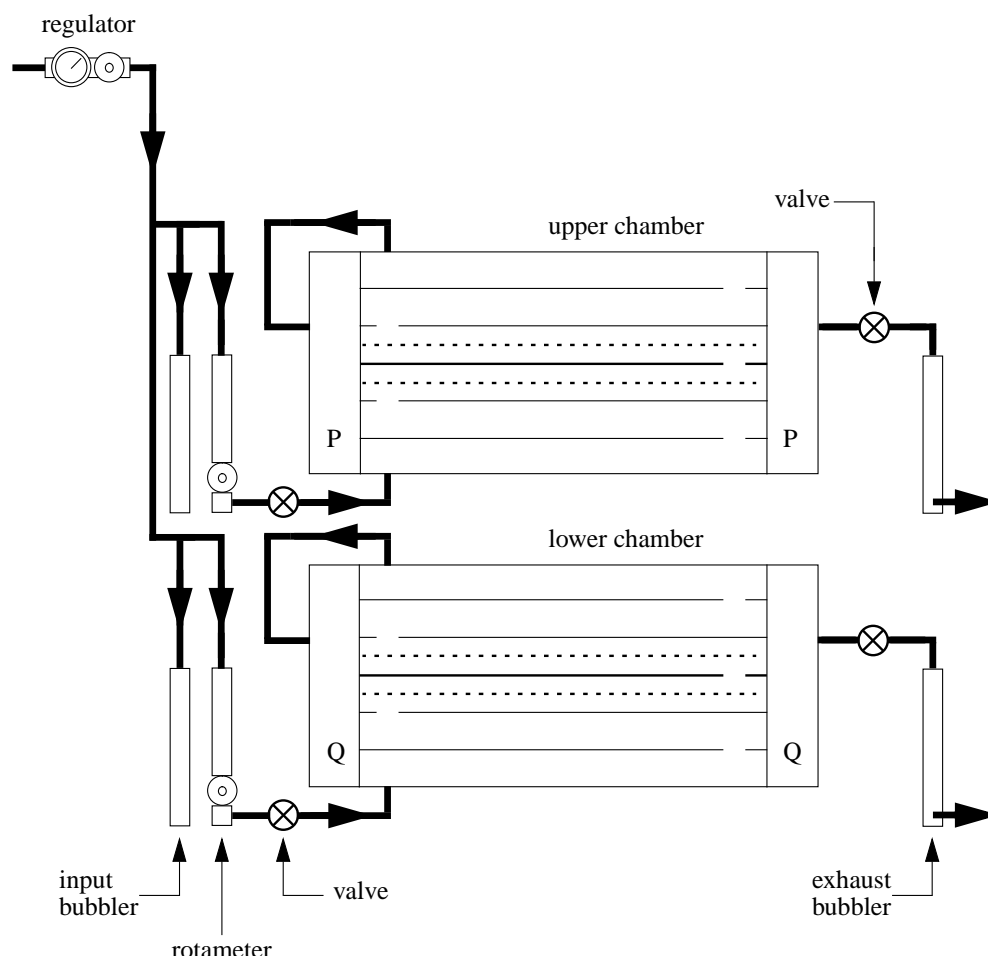


Figure 5.3: Gas flow schematic

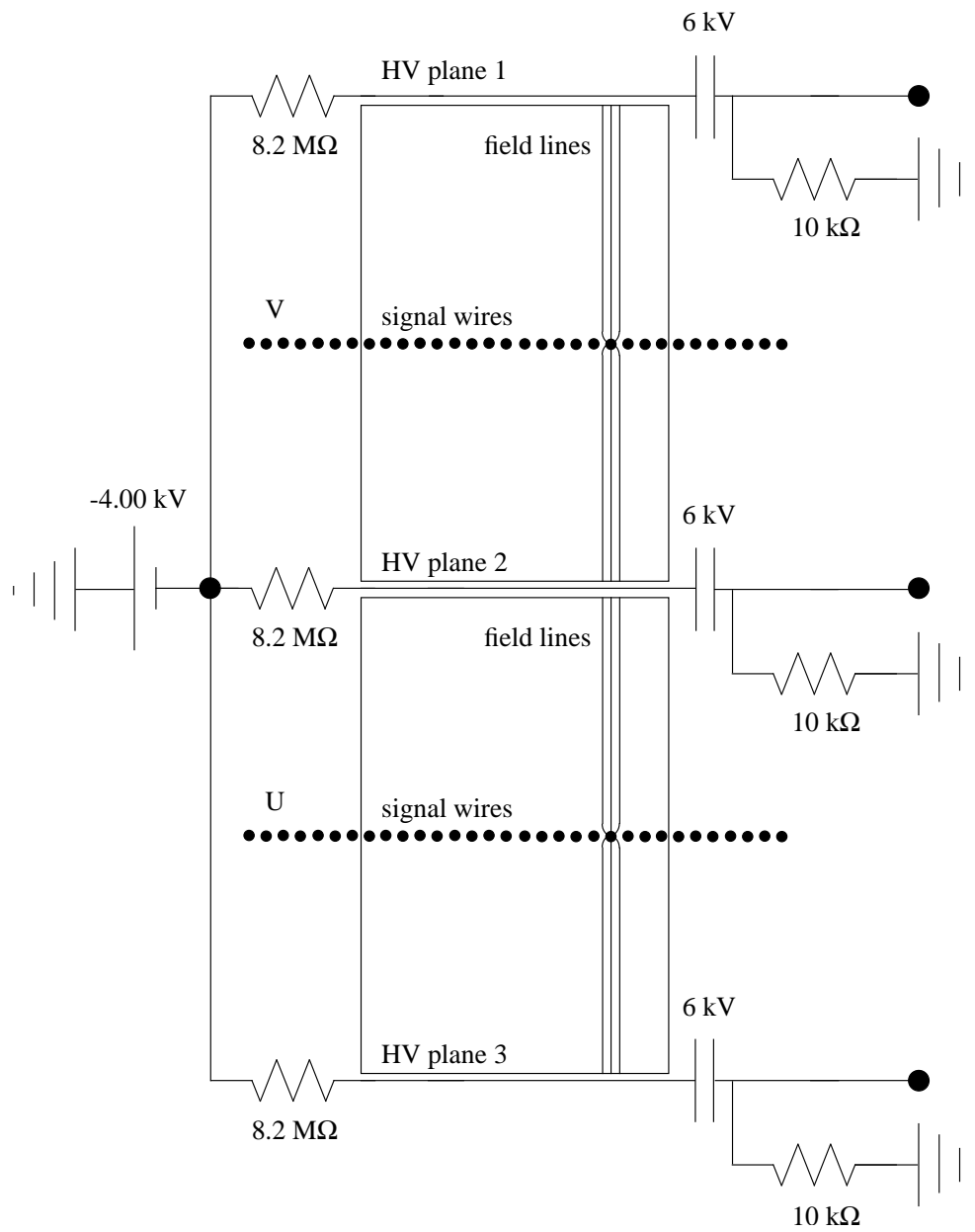


Figure 5.4: VDC overview.

in a NIM bin on the upper level of the space frame. This unit may be controlled either manually or remotely via the EPICS control software, and also provides a monitor of the current drawn (nominally 70 nA) by the VDCs to which it is attached. Connections from the power supply to the Hammond splitter box, as well as from the Hammond splitter box to the VDCs are made using standard SHV connectors on red RG-59/U cable good to 5 kV.

A Kepco ATE 15-3m discriminator power supply provides +3.0 V (92 cards draw ≤ 2 A) and the Kepco ATE 6-100m pre-amp power supply provides ± 5 V nominal to the LeCroy 2735DC pre-amp/discriminator cards used to instrument the chambers via a heavy-duty fuse panel. The precise voltages provided are +5.0 V (92 cards draw 22 A) and -5.2 V (92 cards draw 58 A). These LV supplies are located in the detector hut on the main level of the space frame for the HRS_e and on the upper level of the space frame for the HRS_h. Complete connection schematics and instructions for making or breaking the connections are located on the aluminum Faraday cage protective plates covering the respective interface nodes between the power supplies and the VDCs.

Each VDC wire plane consists of 400 $20\ \mu\text{m}\ \phi$, Au-plated tungsten wires. The first 16 wires on each end of the wire plane are connected to ground for field-shaping purposes. There are 368 wires per wire plane which act as signal wires. Thus, each spectrometer is instrumented with 1472 channels of LeCroy 1877 multihit Fastbus TDCs. These TDCs are located in a Kinetic Systems F050 Fastbus crate with a BiRa FB8189-4 power supply located on the main level of the spectrometer space frame in the detector hut. The connections between the pre-amp/discriminator cards mounted on the VDCs and the TDCs are made with 34-conductor twisted-pair cables. Clip-on ferrites are used to filter noise. A connection schematic is posted on the side of the rack holding the Fastbus crate on the space frame in the detector hut.

Power-up Procedure

1. ensure gas flow has been established in the chambers as previously outlined. If it has not, *STOP RIGHT HERE!* Gas flow must be well-established and steady-state *BEFORE* the HV may be enabled.
2. Ensure that all power supplies as well as the Fastbus crate are off and then connect the LV, HV, and TDC cables.
3. enable the LV. Set points are clearly labeled on the face of the power supplies. Note that they have overcurrent setpoints, and some fine adjustments over the first 30 minutes after a cold start power-up may be required. Appropriate LEDs should all be active on both the power supplies and the pre-amp/discriminator cards.
4. slowly (steps of no more than -300 V) ramp the HV to its nominal set point of -4.00 kV using either the manual or the remote controls. While the trip current is set to 10 μA , do not allow the chambers to draw more than 1 μA during the ramping procedure or serious damage may result. If the power supply trips during the ramping procedure, you are moving too fast. Rezero things and begin the

procedure again. *NEVER USE THE AUTO-RESET FUNCTION.* If the power supply trips again, *STOP IMMEDIATELY AND INVESTIGATE.*

5. enable the Fastbus crate. Appropriate LEDs should all be active.
6. check for poor signal connections evidenced by hot wires (wires counting extremely fast) or dead wires (wires with no counts) using the histogramming software and cosmic rays. Remake any connections as necessary by first powering down the Fastbus crate.

If at all possible, the HV and LV power supplies should be left on continuously if and only if gas is available to the chamber. This avoids time loss to reconditioning and maintains the desirable steady-state operating condition.

5.2.3 Handling Considerations

The VDCs are very delicate devices which are absolutely essential to the instrumentation of the Hall A spectrometers. Thus, extreme care must be exercised whenever they are moved or used.

- Before moving a VDC detector package, ensure that the protective plates are in position. Plates include tapped aluminum sheets to be bolted over the entrance and exit apertures, as well as aluminum sheets which slide in between the two chambers.
- Disconnect and reconnect all TDC cables with extreme care. The conductor pins are relatively fragile, and should one be broken off, repair will be *extremely* difficult.
- When initiating gas flow, pay strict attention to the feedback parameters. Over-pressure may damage the chambers.
- Never attempt to apply HV to the chambers until gas flow conditions have reached steady-state.
- As the amount of heat generated by the pre-amp/discriminator cards is substantial, always make sure adequate cooling is provided before attempting to run. This cooling takes the form of four 12VDC fans mounted in the aluminum Faraday cage.
- When ramping the HV, never allow the chambers to draw more than 1 μ A instantaneously. If they do, something is wrong!

5.2.4 Other Documentation

See the URL⁵.

⁵<http://www.jlab.org/~fissum/vdcs.html>

5.2.5 Safety Assessment

The following potential hazards have been clearly identified.

The High Voltage System The Bertan 377N HV low current power supply provides a nominal -4.00 kV. Red HV RG-59/U cable good to 5 kV with standard SHV connectors is used to connect the power supply to a Hammond splitter box, and then to connect the splitter box to each of the three high voltage planes in a given VDC. A given chamber draws a current from 50-100 nA.

The Low Voltage System Kepco LV power supplies are used for the the LeCroy 2735DC pre-amp/discriminator cards. Each card (23 per chamber) requires +5.0 V (92 cards draw 22 A), -5.2 V (92 cards draw 58 A) and +3.0 V (92 cards draw ≤ 2 A).

Explosive Gas The Ar C₂H₆ chamber gas is explosive and must be handled accordingly. Further, gas flow should be maintained for at least 24 hours prior to the enabling of HV.

High Pressure Gas Bottles The gas used in the chambers is supplied in high pressure (≥ 2000 psi) gas bottles. This confined high pressure gas represents a tremendous (potentially lethal) amount of stored energy.

5.2.6 Responsible Personnel

The following individuals are responsible for chamber problems.

Segal, Jack - x7242, pager 584-7242

Wojtsekhowski, Bogdan - x7191, pager 584-7191

5.3 Trigger Scintillator Counters ^{6 7}

5.3.1 Overview

On each HRS the detector system has two planes of trigger scintillators S1 and S2. The HA detector stack includes an optional third plane, S3. The mounting schemes of these planes are different. S1 is clamped to the detector frame through an additional Al channel, while S2 is assembled on a sub frame, which can slide on rails into the detector frame. S3 has strong a heavy sub frame, which can be mounted on the top of the HA detector frame. Figure 5.5 shows the mounting scheme for S1.



Figure 5.5: S1 mounting

S1 and S2 each consist of six paddles. Each S1 paddle has an active area of 29.5 cm by 35.5 cm. Each S2 paddle has an active area of 54.0 cm by 37.0 cm. The counters are made of 5 mm thick BICRON 408 plastic scintillator and use multi-strip adiabatic light guides which end in a long cylindrical spool. There is an inlet for optical fiber mounted on the side of the cylindrical light guide. Each paddle is viewed by two 2" photo multiplier tubes (Burle 8575). The S1 paddles are installed at a small angle to the

⁶ CVS revision Id: scin.tex,v 1.3 2003/06/06 17:00:27 gen Exp

⁷ Authors: Dr.No <mailto:????@jlab.org>

average plane and overlap by 10 mm. They are supported from PMT housings. The S2 paddles have only 5 mm overlap. Paddles are supported right outside the active area to minimize deflection of the plastic scintillator and the torque applied to the mounting of the PMT housing.

5.3.2 PMT regime and time resolution

High energy electrons passing perpendicular to the S2 detector plane yield about 400-500 photons at the photo cathode of each PMT. In a fresh PMT this leads to 80-100 photo electrons. On HRS the discriminators have a threshold of 45 mV and a typical PMT has gain 3×10^6 . The HV for a fresh PMT should be in the range 1800 to 2000 V. Based on PMT pulse rise time (2.8 ns) and photo electron statistics the time resolution is about 0.2 ns. The propagation time of the light inside the detector is about 10 ns, which needs to be corrected by using track position information.

LeCroy HV 1460 modules are used to supply HV power for the trigger counters. The HV can be controlled from a VT100 terminal connected through a terminal server or through the EPICS system based on the HAC computer. Current HV settings for the trigger counters should be found from a printout of the EPICS control in the last experimental logbook. Figures 5.6 and 5.7 give examples which are included for guidance only. The settings used in the plots may be not correct.

5.3.3 PMT operation monitoring

There are two ways to monitor PMT/detector performance. The first is based on a scaler display program which provides information about PMT counting rates and coincidence counting rates. A large variation of the rates between paddles is an indication of a possible problem. The second technique is to use the analysis code ESPACE and the kumac files developed by K. Takahashi (“kazu” files). This analysis provides amplitude spectra for events with good tracks in the VDC. Histograms of amplitudes and average amplitudes for each PMT are accumulated. For high efficiency of the trigger it is important to keep the average amplitude above 600 channels. Sample spectra are shown in Fig 5.8.

5.3.4 PMT replacement

Because of a large contamination of He in the air around the detectors the quantum efficiency of the PMTs slowly decreases (about 5-10% per month in case of high rate operation). The replacement of a PMT takes about 15-20 minutes.

5.3.5 2” PMT Bases for S1 and S2 Trigger Counters

A schematic diagram of the 2” PMT Base is shown in Figure 5.9. The Base consists of three main components. These are the front tubular housing (06), which encloses the PMT, part of the scintillator counter’s light guide (01), and the mu-metal shield (10).

Right Arm Top											
		S1/S2 Left	S1/S2 Right	Slot 4 Preshower	Slot 5 Preshower	Slot 7 Preshower	Slot 8 Preshower	Aerogel Cerenkov	Aerogel Cerenkov	Gas Cerenkov	
HW/OFF	HW/ON										
Ch 0		-2001	-2051	-1044	-1060	-852	-1083	-21	-20	-2401	
Ch 1		-2000	-1977	-1147	-1148	-1090	-1081	-19	-19	-2427	
Ch 2		-2101	-2071	-1098	-1067	-989	-1071	-18	-23	-2401	
Ch 3		-1972	-1950	-1063	-1077	-1073	-1570	-16	-20	-2501	
Ch 4		-2031	-2003	-1081	-1161	-1067	-1086	-18	-27	-2401	
Ch 5		-2201	-2151	-1112	-1108	-1024	-1011	-20	-22	-2500	
Ch 6		-2051	-1971	-1112	-1083	-1171	-1093	-20	-29	-2351	
Ch 7		-1851	-1952	-1192	-1072	-1571	-1068	-21	-24	-2451	
Ch 8		-1941	-2051	-1025	-1063	-1028	-1095	-18	-24	-2551	
Ch 9		-1901	-2002	-1102	-1075	-1107	-1065	-19	-24	-2501	
Ch 10		-2021	-2021	-1125	-1108	-1088	-1065	-20	-23	-16	
Ch 11		-2101	-2022	-974	-1053	-1109	-1001	-18	-22	-25	

Figure 5.6: EPICS HV HRSR summary screen.

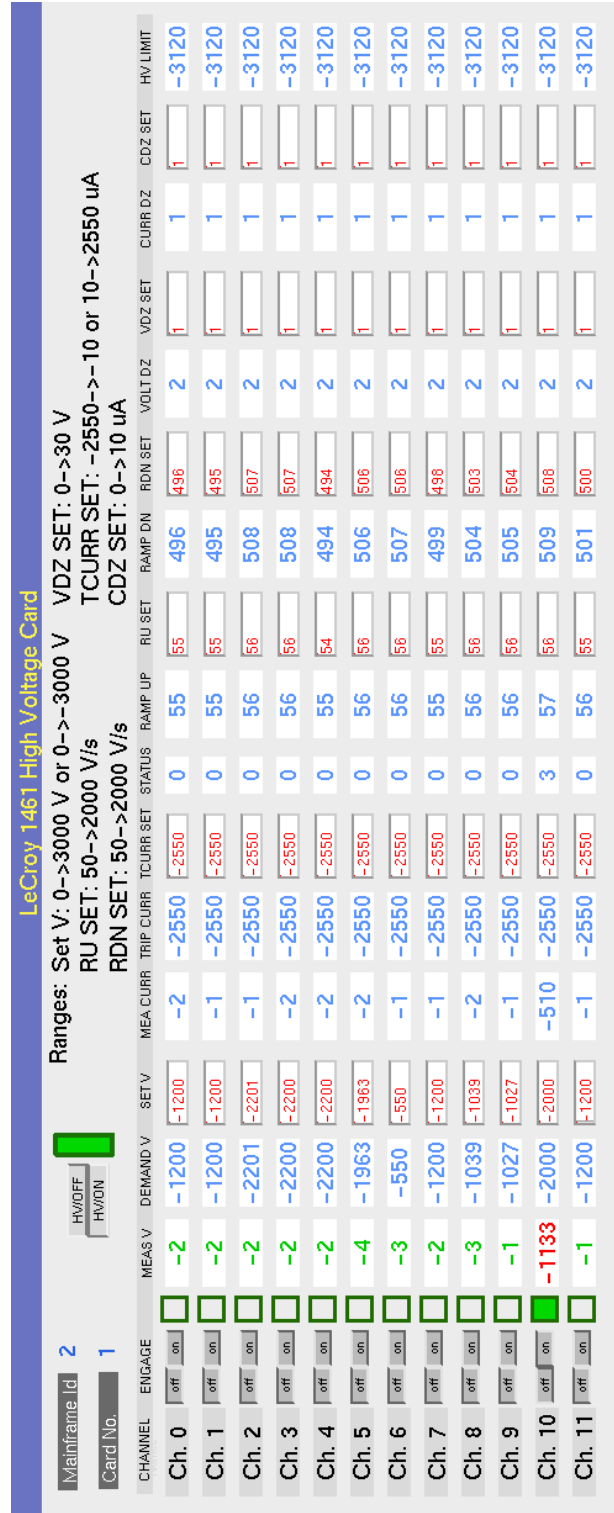


Figure 5.7: HV screen for a single card.

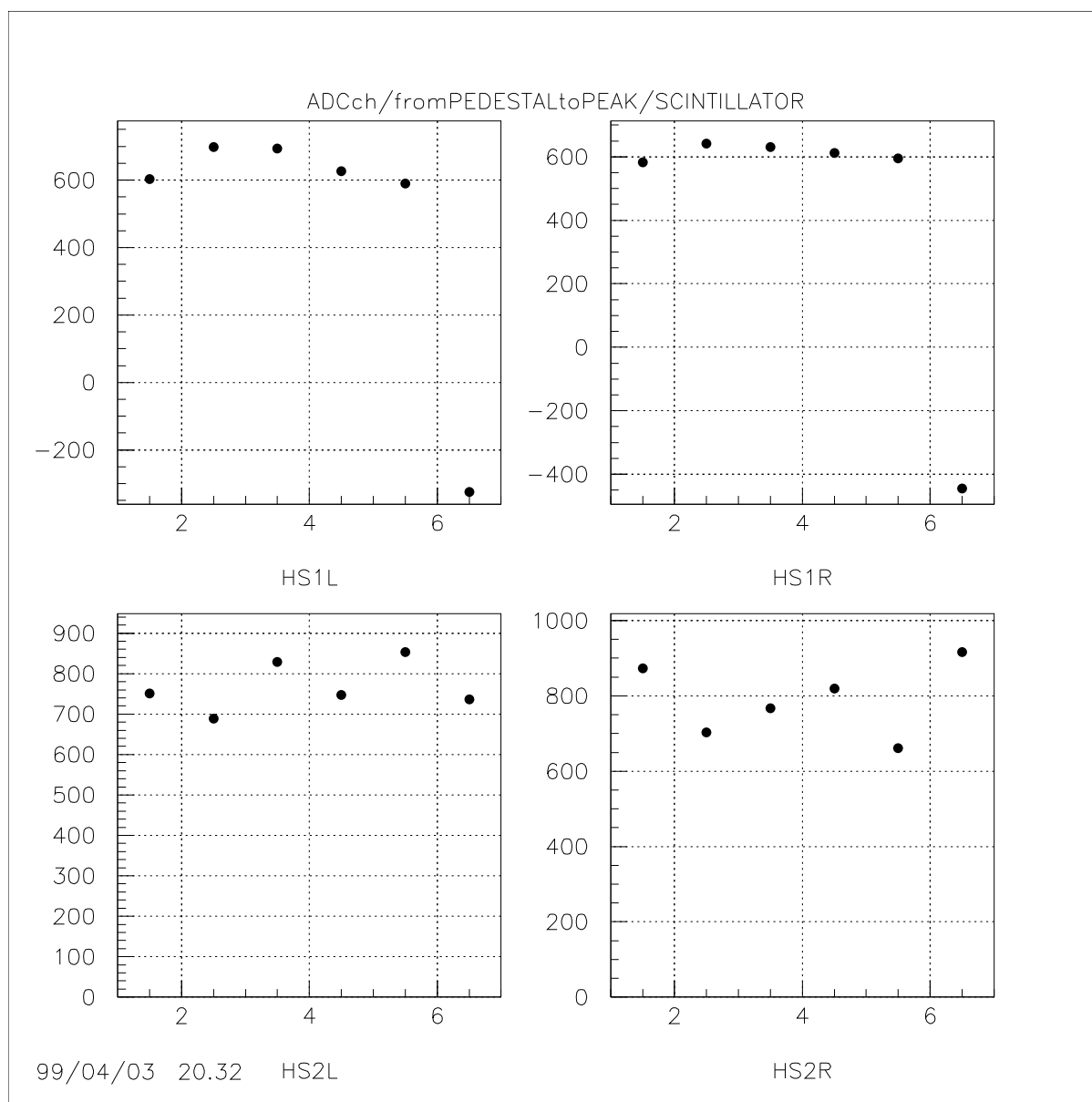


Figure 5.8: Average Amplitudes of HA Trigger Counters.

The actual base with the socket and the dynode chain is a separate part, actually an assembly of parts (09-19). The rear tubular housing (07) completes the assembly and encloses the dynode chain and wiring. The three main sections join at the coupling nut (14), which threads partly inside the front tubular housing, while the rear tubular housing threads on the remaining part.

The PMT and the electronic amplification components are mounted on a P.C. board (15) which is enclosed in an aluminum Faraday cage. This assures rigidity and protection from stray RF fields. The mu-metal shield is at cathode potential to minimize the dark current due to capacitive discharge in the photo cathode glass window.

5.3.6 Handling Considerations

Assembly Instructions Unscrew the rear tubular housing from the coupling nut and then unscrew the front tubular housing from the coupling nut. Remove the mu-metal shield (10) from the retainer ring (12) by loosening the nylon locking set screw (11). After insertion of the PMT in the socket, install the mu-metal shield and make sure it sits squarely in the bottom of the socket base (13).

WARNING: The mu-metal shield should NEVER be assembled in the base without the plastic insulator ring (09). Electrical shock may result if someone touches the outside housings under such a condition. The plastic insulator ring also serves as a mechanical alignment aid to keep the mu-metal shield centered within the front tubular housing.

Tighten the nylon locking set screw but don't over do it and strip the nylon threads in the process. The mu-metal shield has a solid friction fit in the copper ring inside the retainer ring to make good electrical contact.

Screw the base assembly, with the PMT and mu-metal shield attached, back into the front tubular housing, up to the half way point of the threads in the coupling nut. The PMT socket and dynode chain assembly (15) is spring loaded (16) so one can see how much compression the light guide will induce on this assembly, thus assuring a good contact with the PMT without the risk of damage to the latter. Insert the collet nut (03) and the inner collet (04) onto the light guide as shown in Figure 5.9. Position the outer collet inside the entrance to the front tubular housing and check that it matches the direction of the cone to that of the outer collet. Smear a thin layer of optical grease on the light guide and insert the latter into the inner collet until it makes contact with the PMT. This can be verified by observing the movement of the socket against the, now slightly compressed, springs. Insert the outer collet into the inner one and screw the collet nut making sure the springs remain slightly compressed in the process. Use the special tool to tighten the collet nut until the light guide cannot be moved in or out.

Replace the rear tubular housing by screwing it all the way into the coupling nut. Insert the foam plastic light stop (02) between the collet nut and the light guide. The mechanical assembly is now complete.

The Electronic Amplification Chain The arrangement of the resistor dynode chain is shown in Figure 5.10. The cathode is connected to the mu-metal shield through a 10

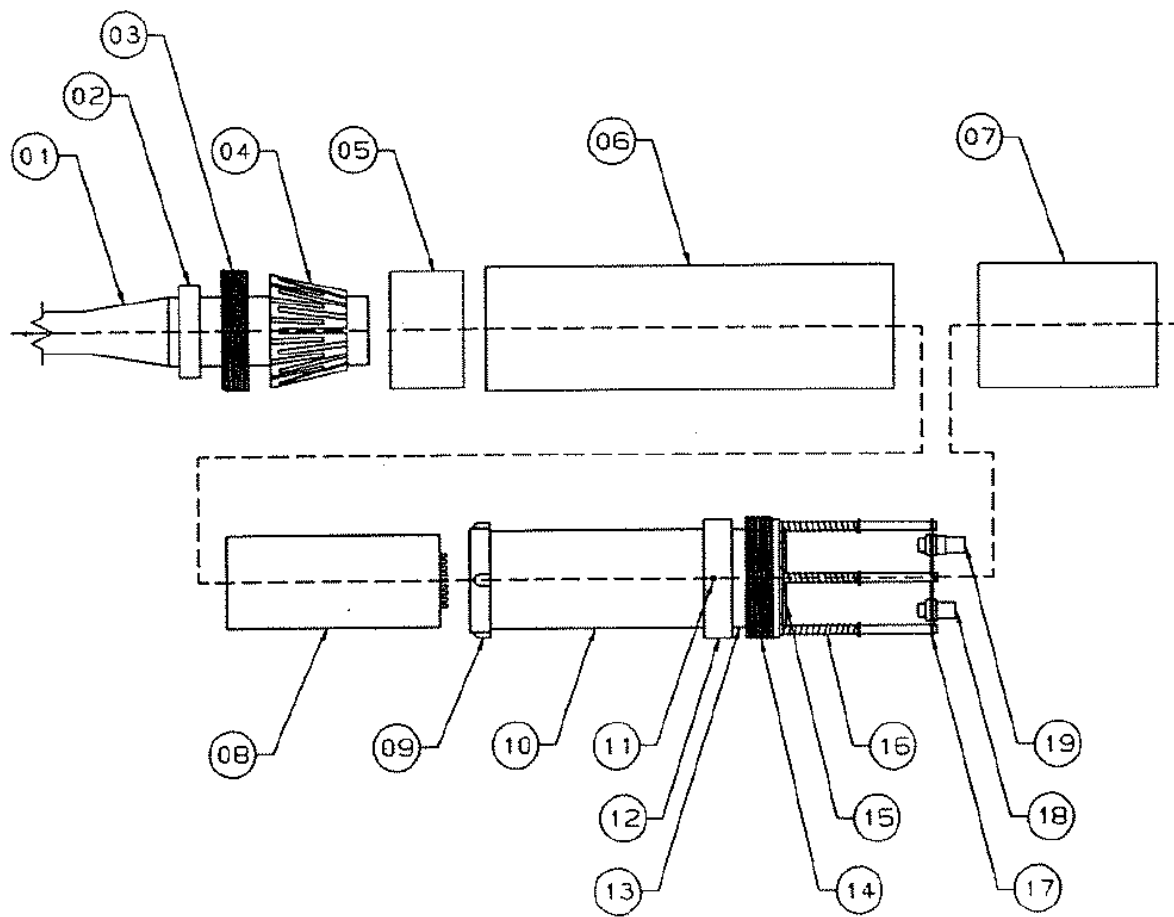


Figure 1

2 inch PMT Base Assembly

Figure 5.9: The 2" PMT base used in S1 and S2 trigger scintillators.

MΩ resistor, in addition to the 1 MΩ resistor between the cathode and the negative HV. The dynode chain incorporates an adjustable potentiometer (0-500 Ω) to allow a match between the PMT and the external load, in order to eliminate after-pulse ringing. This potentiometer should be adjusted at first to 250 Ω and then make fine adjustments as needed by observing the anode pulses on the oscilloscope for critical matching. It is not advisable to do the adjustments with HV on. Instead, the process should be done with HV off; remove the rear tubular housing, adjust the potentiometer, replace the rear housing, and then turn the HV on again. Iterate until the matching is accomplished. In addition to the obvious safety concerns, one does not want to remove the light sealing rear housing from an active PMT and induce a large light leak which could destroy the PMT.

BURLE 8575 PHOTOMULTIPLIER TUBE DYNODE CHAIN

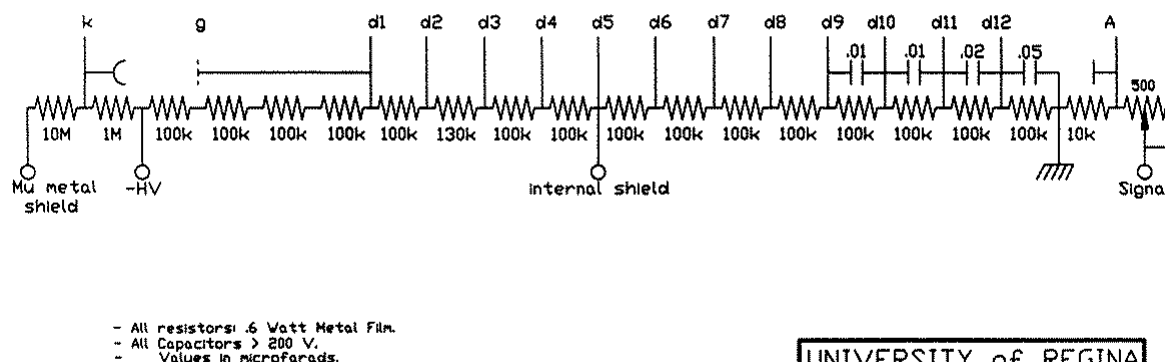


Figure 2

Figure 5.10: The 2" PMT base used in S1 and S2 trigger scintillators.

Both 2" and 5" bases have been extensively tested under beam conditions. They have several safety related features but these cannot protect anyone who is bent on violating operating procedures and common sense. They allow the removal of the PMT/Base assembly, for repairs of the electronics or replacement of a PMT, without decoupling the housing and collets from the light guide. Thus, replacement of PMTs can be done in minutes without the need to remove the scintillator counters from their subframes.

5.3.7 5" PMT Bases for S3 Counters

The general layout of the 5" bases is similar to that of the 2" bases described above. It consists of a front tubular housing and a rear tubular housing, both made out of aluminum. They join at a coupling nut, as shown in the schematic diagram of Figure 5.11. The actual base where the PMT, μ -metal shield, and the electronic dynode amplification chain are located, is different. The corresponding middle section, incorporating the above components, is made out of a moulded structure used in both the 5" bases and the aerogel Cerenkov counters. The PMT socket is moulded integral to the section and it is also spring loaded. The collets are different, due to the size of the light guide, but the method of assembly is very similar to that of the 2" base.

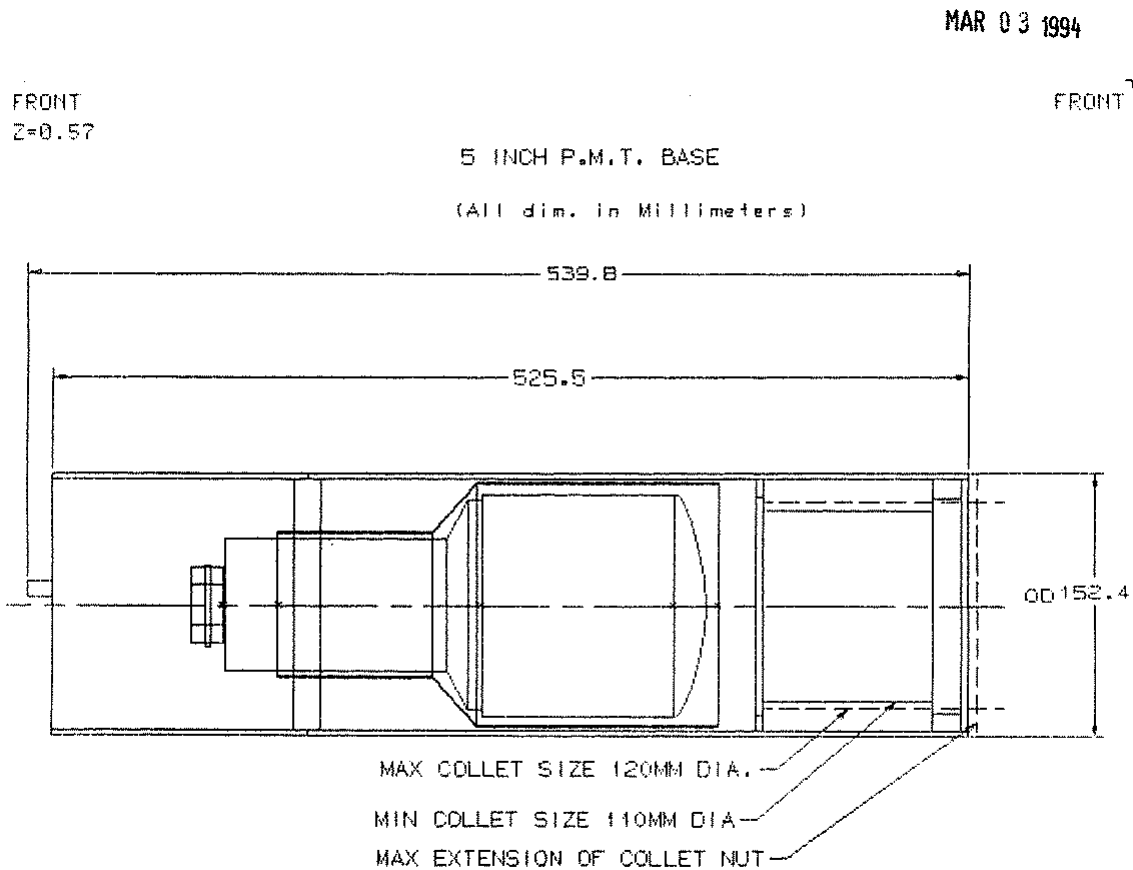


Figure 3

Figure 5.11: The 5" PMT base used in S3 trigger scintillators.

Assembly Instructions The collet assembly consists of several expanding rings, one set of solid tapered and the other a spring collet. They are placed on top of each other, alternating between the two kinds, with a spring collet on the top facing the scintillator and the collet nut. As the collet nut is screwed in, it presses against the assembly and the spring collets slide inward against the tapered solid ones, thus clamping against the light guide. Care should be taken, when placing these two different kind of collets inside each other, so as not to align the gaps in the plastic and create light leaks. The collets are not continuous rings, otherwise they would not be compressible, and the gaps can allow light all the way into the PMT if they are aligned.

The collet nut is placed first around the light guide and the successive layers of the moulded collets are then placed around the light guide; one should make sure that enough free length of exposed light guide remains to enter the housing to slightly compress the PMT and base assembly, as in the case of the 2" base. Once the slight compression of the spring loaded PMT-socket assembly is verified, the set of collet rings is moved to enter the housing and rest firmly against the snap/stop ring inside the front tubular housing. Then the collet ring is screwed in using the special tool until the light guide is firmly bedded in the housing and cannot be moved in or out. The remaining procedure is the same as that of the 2" base.

Due to the two diameter shape of the 5" PMT and its mu-metal shield, insertion of the PMT pins into the socket is a blind operation. It has to be done by feel and experience; the pins can only go in a specific PMT-socket geometry and it needs experience to learn when the correct alignment has been achieved. Let someone who has experience do it, bending of the socket pins at the base of the PMT results in destroyed PMTs, and they are expensive.

WARNING: The plastic insulator sleeve inside the front tubular aluminum housing should be in place BEFORE the mu-metal shield/PMT assembly is inserted. Failure to assure the proper location of the insulating plastic sleeve may result in electrical shock.

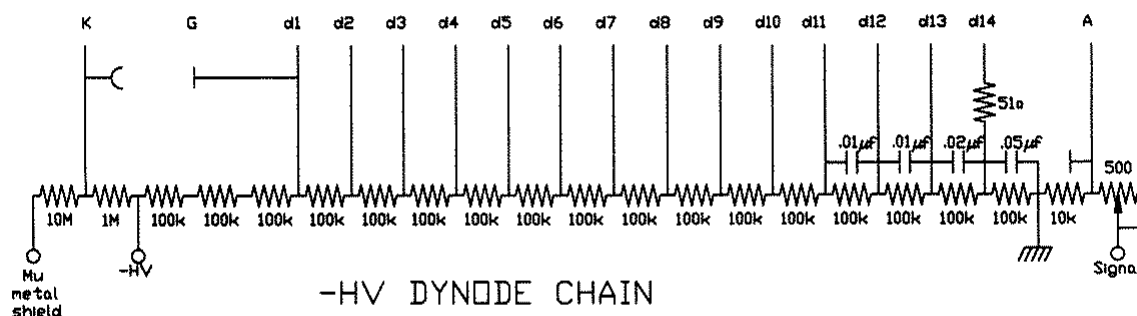
The Electronic Amplification Chain The dynode amplification chain is mounted on a PC board, as is the case of the 2" base. A schematic diagram of the resistor chain is shown in Figure 5.12. As in the case of the 2" base, it incorporates an adjustable potentiometer (0-500 Ω) and the nominal critical matching value is 90 Ω . It has, in addition, a 51 Ω resistor in series with the 14th dynode, to further improve the shape of the anode pulse. A safe -HV to start with is -1.8 kV; it provides the best timing resolution with adequate pulse height for electrons during beam testing.

5.3.8 Safety Assessment

WARNING: The bases are high voltage devices and should only be handled by competent people who can exercise common sense.

The maximum voltage for both the PMTs and dynode chain is 3 kV. In actual use, however, there should be no need to exceed the 1.8-2.1 kV operating parameters, since both PMTs and dynode chain have high gain. Nevertheless, the bases are high voltage

BURLE 8854 PHOTOMULTIPLIER TUBE DYNODE CHAIN



- All resistors: .5 Watt Metal Film.
- All Capacitors > 200 V.
- Values in microfarads.

Figure 4

UNIVERSITY of REGINA	
Faculty of Science Electronics Shop	
Title: Burle 8854 P.M. Tube Dynode Chain	
Date: 17/Dec/90	Page: 1 of 1
Notes: -H.V. version 1. With matching pot.	
File: 8854.dwg	

Figure 5.12: The 5" PMT base used in S3 trigger scintillators.

devices and care should be exercised during handling and setup. The external aluminum parts, the front and rear housing, and the back plate (17), are all grounded via the ground of the BNC (18) and SHV (19) connectors. Since the back plate is connected to the coupling nut via the three steel posts, the front plate is also grounded via the coupling nut and the back plate. Common sense, however, dictates that the bases are not to be handled while under high voltage, even when multiple grounding connections are provided.

The mu-metal shield is also under high voltage, since it is connected to the cathode. Electrical isolation between the mu-metal shield and the front tubular housing is assured by the high dielectric retainer ring (12) and the plastic insulator (09) at the free end of the mu-metal shield. The air gap between the mu-metal shield and the front tubular housing is 6 mm, thus the breakdown value (18 kV) far exceeds the maximum 3.0 kV of the PMT.

In the event that the mu-metal shield is inserted without the plastic insulator ring,

or some oaf decides to operate the base without the outside housings, the $11\text{ M}\Omega$ resistors between the -HV and the mu-metal shield will restrict the current flow through the mu-metal shield (and the oaf's hands) to less than 0.2 mA with -2.1 kV on the base.

5.3.9 Responsible Personnel

The following individuals are responsible for operation of the trigger counters.

Segal, Jack - x7242

Wojtsekhowski, Bogdan - x7191

5.4 Lead Glass Shower Counters ^{8 9}

5.4.1 Overview

Electromagnetic shower counters offer a useful means of particle identification (PID) [10]-[11]. Shower counters complement other means of PID such as time-of-flight (TOF) or threshold Cerenkov counters, due to the independent physical processes responsible which result in different detector limitations [12]. Independent PID allows multiple detectors (*i.e.*, a Cerenkov counter followed by a shower counter) to obtain excellent rejection ratios that are the product of the individual rejection ratios.

Shower counters measure the energy deposited by the incoming particle. The detected light output is linearly proportional to the energy lost by the incoming particle. Electromagnetic showers are stopped in the counters, whereas hadronic showers, due to the longer hadronic mean free path, are not. Looking at the longitudinal distribution of the energy deposited in the calorimeter differentiates between electromagnetic and hadronic showers and therefore identifies the incident particle.

Typical pion rejection with a lead glass counter is of the order of 100-1000:1 in the 1 to 10 GeV region [13]. The Hall A electromagnetic shower counter is meant to offer rejection ratios better than 100:1 [14]. The limitation in using a shower counter comes from separating the tails of the distributions, and is therefore dependent on energy resolution. At higher energy the relative resolution of a shower counter improves, leading to better separation between distributions. Conversely, other techniques perform worse at higher energy. The TOF separation for a given path length decreases, and above 4 GeV/c pions can trigger a threshold CO₂ Cerenkov counter operated at standard temperature and pressure (STP) [13]. [The threshold for a CO₂ Cerenkov counter at STP is $\gamma = 34.1$, meaning that for an electron the threshold is just over 17 MeV, while for a pion the threshold is just over 4 GeV/c momentum].

A Cerenkov counter is routinely capable of pion rejection of the order of 1000:1 at CEBAF energies [13]. A combination of successive Cerenkov counters might achieve higher rejection ratios. However this only works if the backgrounds in the two devices are uncorrelated. A knock-on electron which triggers the first Cerenkov counter and travels forward through both detectors will also trigger the second. Independent PID provided by a measurement of the particle energy in a shower counter offers a solution to this problem of correlated backgrounds. Used in conjunction with a threshold Cerenkov counter, the combination can achieve rejection ratios of 5×10^5 [14].

The Hall A electron spectrometer is equipped with a 2-layer, segmented shower counter. The first layer, the so-called “pre-shower” counter is made of 48 blocks of TF1 lead glass. Each block is nominally 10 cm by 10 cm by 35 cm long. The second layer, the so-called “total absorber” counter is nominally 15 cm by 15 cm by 35 cm viewed head-on by the beam.

Operation of the shower counter requires the application of High Voltage (HV) across

⁸ CVS revision Id: shower.tex,v 1.3 2003/06/06 17:00:27 gen Exp

⁹Authors: Dr.No <mailto:????@jlab.org>

the photomultiplier tubes and bases, which are mounted on the back of the shower counter blocks for the total absorber and on the sides of the shower counter in the case of the pre-shower, within the confines of the protective aluminum support frame.

As charged particles pass through the lead glass of the shower counter, they produce electron-positron particle-antiparticle pairs. These particles in turn both produce additional particles and Cerenkov light which is collected in the phototubes. The pulses are then amplified, delayed and sent to ADCs, which are gated by the overall event trigger. The ADCs are read out by the *CODA* acquisition software. The data are histogrammed online by the *DHIST* software. In-depth offline data analysis requires the *ESPACE* software.

5.4.2 Operating Procedures

Power Supplies and Electronics Procedures The HV power supplies and readout electronics associated with the HRS VDCs are all commercially designed. The reader is directed towards the manuals made available by the manufacturer for the detailed information not provided here.

The LeCroy HV power supply provides -1500 V nominal to the total absorber and 1200 V to the preshower. The power supply is located in the detector hut in a NIM bin on the upper level of the space frame. This unit may be controlled either manually or remotely via the *EPICS* control software, and also provides a monitor of the current drawn by each phototube to which it is attached. Connections from the power supply to the base are made using standard SHV connectors mounted on red RG-59/U HV cable good to 5 kV. Typical values of the high voltages are shown in the tables for both the pre-radiator and the total absorber.

If at all possible, the HV and LV power supplies should be left on continuously. This allows the tube noise to quiet down after high voltage is applied and the temperature of the base components stabilizes.

Signal Handling, Summing, Amplification and the Multiplexer The upstairs electronics racks hold two NIM bins containing the summing modules of the multiplexer. The output of these is sent to the ADCs. Both the individual channels and the sum of every six channels is sent into an ADC where it can later be analyzed by the software. The operations manual for the multiplexer was written by H. Breuer (UMd) and is available from him upon request.

The detector signals are physically plugged into the ADC channels and connected to the signal wires labelled as shown in the diagrams below, for both the preshower counter and the total absorber counter.

5.4.3 Handling Considerations

The shower counters are very delicate devices which are easily damaged. Thus, care must be exercised whenever they are moved or used.

Nominal High Voltage Settings for Electron Arm PreShower

Table 1: (Oct 10 1997)

PreSh. Block	HAC5 HV slot chan	HV (V)	PreSh. Block	HAC5 # HVslot chan	HV (V)
1L	4.0	1130	1R	7.0	960
2L	4.1	1255	2R	7.1	1180
3L	4.2	1195	3R	7.2	1075
4L	4.3	1175	4R	7.3	1150
5L	4.4	1200	5R	7.4	1140
6L	4.5	1175	6R	7.5	1105
7L	4.6	1190	7R	7.6	1275
8L	4.7	1280	8R	7.7	1175
9L	4.8	1100	9R	7.8	1100
10L	4.9	1160	10R	7.9	1175
11L	4.10	1210	11R	7.10	1110
12L	4.11	1025	12R	7.11	1210
13L	5.0	1100	13R	8.0	1160
14L	5.1	1200	14R	8.1	1180
15L	5.2	1115	15R	8.2	1145
16L	5.3	1110	16R	8.3	1180
17L	5.4	1275	17R	8.4	1180
18L	5.5	1185	18R	8.5	1095
19L	5.6	1165	19R	8.6	1200
20L	5.7	1165	20R	8.7	1165
21L	5.8	1175	21R	8.8	1205
22L	5.9	1165	22R	8.9	1160
23L	5.10	1200	23R	8.10	1155
24L	5.11	1080	24R	8.11	1240

Figure 5.13: Typical values of the preshower counter high voltages.

Nominal High Voltage Settings for Electron Arm Shower

Table 1: (Oct 10 1997)

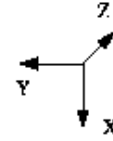
Sh Blk	HAC6 HV slot.. chan	HV (V)	Sh Blk	HAC6 HV slot.. chan	HV (V)	Sh Blk	HAC6 slot.. chan	HV (V)	Sh Blk	HAC6 slot.. chan	HV (V)
1	1.0	1425	25	4.0	1470	49	7.0	1450	73	10.0	1500
2	1.1	1415	26	4.1	1395	50	7.1	1540	74	10.1	1315
3	1.2	1480	27	4.2	1475	51	7.2	1460	75	10.2	1440
4	1.3	1375	28	4.3	1470	52	7.3	1550	76	10.3	1550
5	1.4	1480	29	4.4	1400	53	7.4	1520	77	10.4	1395
6	1.5	1455	30	4.5	1435	54	7.5	1585	78	10.5	1445
7	1.6	1510	31	4.6	1440	55	7.6	1375	79	10.6	1575
8	1.7	1360	32	4.7	1460	56	7.7	1530	80	10.7	1415
9	1.8	1420	33	4.8	1430	57	7.8	1335	81	10.8	1415
10	1.9	1490	34	4.9	1580	58	7.9	1415	82	10.9	1380
11	1.10	1500	35	4.10	1405	59	7.10	1440	83	10.10	1600
12	1.11	1385	36	4.11	1515	60	7.11	1380	84	10.11	1540
13	2.0	1555	37	5.0	1385	61	8.0	1310	85	11.0	1480
14	2.1	1440	38	5.1	1490	62	8.1	1410	86	11.1	1395
15	2.2	1430	39	5.2	1425	63	8.2	1455	87	11.2	1400
16	2.3	1435	40	5.3	1435	64	8.3	1275	88	11.3	1465
17	2.4	1440	41	5.4	1465	65	8.4	1550	89	11.4	1455
18	2.5	1450	42	5.5	1350	66	8.5	1365	90	11.5	1440
19	2.6	1585	43	5.6	1470	67	8.6	1365	91	11.6	1500
20	2.7	1400	44	5.7	1415	68	8.7	1370	92	11.7	1700
21	2.8	1340	45	5.8	1390	69	8.8	1380	93	11.8	1550
22	2.9	1400	46	5.9	1365	70	8.9	1800	94	11.9	1435
23	2.10	1420	47	5.10	1380	71	8.10	1355	95	11.10	1550
24	2.11	1495	48	5.11	1445	72	8.11	1550	96	11.11	1500

Figure 5.14: Typical values of the total absorption counterhigh voltages.

PreShower detector map (effective from May 1997)

H. Voskanian (voskania@ccbsf.gov)

1L	1A4	(22 : 3)	1A1	(22 : 0)	1R	1
2L	1A5	(22 : 4)	1A2	(22 : 1)	2R	3
3L	1A6	(22 : 5)	1A3	(22 : 2)	3R	5
4L	1B4	(22 : 9)	1B1	(22 : 6)	4R	7
5L	1B5	(22 : 10)	1B2	(22 : 7)	5R	9
6L	1B6	(22 : 11)	1B3	(22 : 8)	6R	11
7L	2A4	(22 : 15)	2A1	(22 : 12)	7R	13
8L	2A5	(22 : 16)	2A2	(22 : 13)	8R	15
9L	2A6	(22 : 17)	2A3	(22 : 14)	9R	17
10L	2B4	(22 : 21)	2B1	(22 : 18)	10R	19
11L	2B5	(22 : 22)	2B2	(22 : 19)	11R	21
12L	2B6	(22 : 23)	2B3	(22 : 20)	12R	23
13L	3A4	(22 : 27)	3A1	(22 : 24)	13R	25
14L	3A5	(22 : 28)	3A2	(22 : 25)	14R	27
15L	3A6	(22 : 29)	3A3	(22 : 26)	15R	29
16L	3B4	(22 : 33)	3B1	(22 : 30)	16R	31
17L	3B5	(22 : 34)	3B2	(22 : 31)	17R	33
18L	3B6	(22 : 35)	3B3	(22 : 32)	18R	35
19L	4A4	(22 : 39)	4A1	(22 : 36)	19R	37
20L	4A5	(22 : 40)	4A2	(22 : 37)	20R	39
21L	4A6	(22 : 41)	4A3	(22 : 38)	21R	41
22L	4B4	(22 : 45)	4B1	(22 : 42)	22R	43
23L	4B5	(22 : 46)	4B2	(22 : 43)	23R	45
24L	4B6	(22 : 47)	4B3	(22 : 44)	24R	47



AMP#AMP-Ch (ADC Slot# : Chan #)

Figure 5.15: Map of the Pre-shower counter detectors.

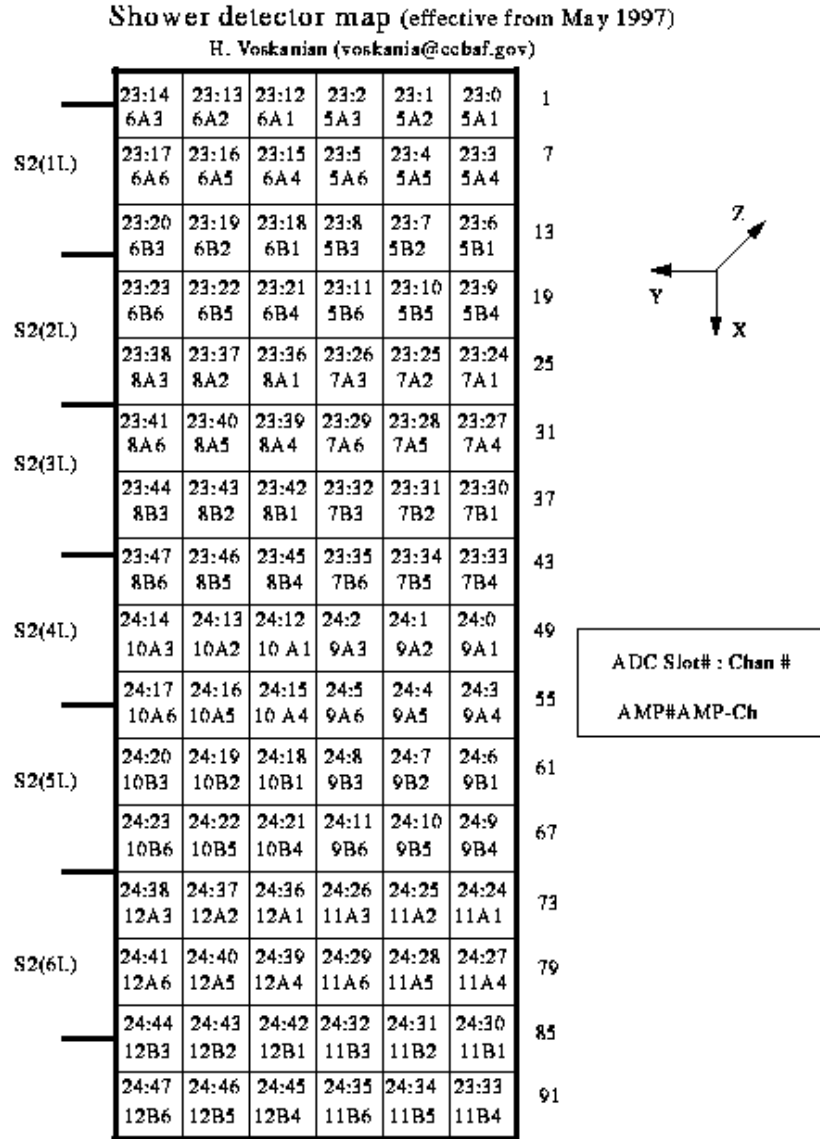


Figure 5.16: Map of the shower counter detectors.

- Before turning on the high voltage for the shower counters (HAC5 for the preshower and HAC6 for the total absorber), check the shower counter log book located in the Hall A counting house for the latest values of the high voltage.
- Never disconnect or connect all the high voltage to the bases with the high voltage power turned on. Doing so will damage the bases (the zener diodes are destroyed).
- Never service the lead glass with the high voltage on. The high voltage poses a safety hazard.
- Never drop anything onto the bases and tubes; they are extremely fragile. They should not be used as support or to hold any weight. Also, do not drop the lead glass blocks. They will be damaged or destroyed.
- When ramping the HV, keep an eye on the current drawn by the individual bases. A light leak in the wrapping will produce a large current ($> 1\mu\text{A}$ at low voltages (1 kV). If the tubes draw an excess amount of current turn them off and check for leaks in the wrapping.

5.4.4 Safety Assessment

The following potential hazards have been clearly identified.

The High Voltage System The LeCroy 1443 HV crate equipped with LeCroy 1461N negative high voltage cards supplies provides up to 3.3 kV of low current power. Red HV RG-59/U cable good to 5 kV with standard SHV connectors is used to connect the power supply to the photomultiplier tube voltage divider bases. A given base on the TA draws typically 500-600 μA of current with the high voltage on at between 1400 and 1500 V. The PS bases typically draw 900 μA with the high voltage on at between 1100 and 1200 V.

The Lead Glass Support Structure The lead glass shower counters are mounted on top of the space frame for the detectors. Access for servicing the shower counters requires climbing on top of the support frame. Only the responsible personnel identified below should attempt to service the shower counter; such work requires proper safety precautions and prior training/experience.

The Lead Glass blocks The lead glass shower blocks and tubes weigh approximately 70 – 80 pounds apiece. Lifting, replacing, or moving such blocks should be done properly to avoid muscle problems and damage to the blocks.

5.4.5 Authorized Personnel

The following individuals are authorized to work on shower counters.

Breuer, Herbert - 301-405-6108

Markowitz, Pete - x7237, 305-348-1710

Segal, Jack - x7242

Voskanyan, Hakob - x5105

Wojtsekhowski, Bogdan - x7191

5.4.6 Software Algorithms

The purpose of the shower cluster reconstruction in the Preshower and the Shower detector is to:

- Define all clusters of fired blocks, which belong to the showers, registered in the detector;
- Calculate parameters of showers in the detector: energy deposition of showers, X and Y coordinates of the shower center;
- Set parameters and identifier of the so-called “main” cluster.

Cluster in the shower detector is determined as follows:

- Cluster is a group of continuous blocks;
- Cluster can occupy a maximum of 6 (2×3) blocks in the case of Preshower and 9 (3×3) blocks in the case of Shower;
- Central block is defined as the block that has maximum energy deposition.

The “main” cluster in Preshower/Shower is the cluster with the biggest energy, which is coincident with the “golden track”, or coincident with some Shower/Preshower cluster. Coincidence of the cluster with the “golden track” means that the distance between the shower cluster center and crossing point of “golden track” with the detector plane is less than a certain magnitude. Coincidence of the Preshower and Shower clusters means, that distance between the clusters centers is less than a certain magnitude (it is assumed that both of these points are on the same Z -plane).

The shower clusters reconstruction in Preshower and Shower is performed by the following steps:

1. Sort fired blocks in order of decreasing deposited energy;
2. Pick out the block with maximum energy deposition and all fired blocks in its arrangement (2×3 blocks for Preshower, 3×3 blocks for Shower), as belonging to one cluster;
3. Remove all blocks associated with the found cluster from further consideration;
4. Repeat steps 2 and 3, until all of the fired blocks are associated with a cluster;

5. Calculate energy deposition, X and Y coordinates of each cluster and sort clusters by decreasing energy deposit;
6. Define coordinates of crossing point of “golden track” with detector plane in detector local coordinate system;
7. Analyze geometrical position of the “golden track” point on the detector plane and cluster centers in order to determine the “main” cluster and to set its parameters and identifier.

Energy deposition E , X and Y coordinates of the shower center are calculated by the formulas:

$$E = \sum_{i \in M} e_i, \quad X = \sum_{i \in M} e_i \cdot x_i / E, \quad Y = \sum_{i \in M} e_i \cdot y_i / E,$$

where: i — number of detector block, included in the cluster; M — set of blocks numbers, included in the cluster; e_i — energy deposition in block i of detector; x_i, y_i — X and Y coordinates of center of block i of detector.

The shower cluster reconstruction algorithm described above has been implemented by the ESPACE analysis subroutine **tot_shower**. A complete description of the program as well as information about the ESPACE routines and kumac files used to perform the analysis, photographs of the detectors and more information can be found at the URL

¹⁰

¹⁰http://www.jlab.org/~armen/sh_web_page/welcome.html

5.5 Aerogel CherenkovCounter ^{11 12}

5.5.1 Overview

Each High Resolution Spectrometer detector package includes a single silica aerogel Cherenkovcounter of the compact reflection mirror design, which was dictated by the available space (36.3 cm along the incident particle direction). In addition, the high singles rates expected in Hall A are better handled with segmented detectors covering the focal plane, which requires short pulse decay times. Even though the diffusion length in silica aerogel can be quite short for low λ light generated in the SiO_2 radiator [15], enough directionality remains in the visible λ region, where the selected PMTs have good quantum efficiency, to make light collection with mirrors an attractive and practical alternative.

An effective segmentation of the aerogel Čerenkov counter, matching the segmentation of the trigger scintillators, can be used to separate multiple tracks through the focal plane and will allow an additional element of selectivity and track sensitivity in the focal plane instrumentation. This means that specific sections of the focal plane can be physically disabled from the trigger, if the experimental conditions require it. It will also provide the capability of identifying and separating pions and protons traversing the focal plane trigger scintillators and the vertical drift chambers (VDCs) within the resolving time of the system (double hits). For example, in the offline analysis, the aerogel counter PMT with the highest number of photoelectrons can be matched with the trigger counter and VDC information to identify the actual path of a pion, thus separating it from a simultaneously detected proton, which has no Cherenkovsignature. Such a capability of double hit resolution is not possible with diffusion Cherenkovcounter designs, because the photon collection efficiency does not have a strong correlation with the incident particle track within the aerogel material.

The requirement for segmentation, in addition to supplementing the information on the individual particle position along the focal plane, also couples well with the desirability of increasing the active solid angle viewed by the PMTs in the counter. Although the photon detection probability is not as directly proportional to the solid angle covered by PMTs as in the case of a diffusion box, clearly, the larger the effective coverage, the higher the probability will be that a photon will end up on a PMT. Given the divergence of the beam envelope incident on the aerogel, and the diffusion of the light in the low λ region by the aerogel material, an increase in the area covered by PMTs results in an increase in the number of photons detected. As a result, a total of 26 PMTs are used in the counter, as shown in figure 5.17, with minimal spacing between their μ -metal shields (2.8 mm). The total area covered by the PMT photocathode windows comprises 72% of the area of the counter opposite the planar parabolic mirrors. A cross sectional schematic of the detector is shown in figure 5.18, clearly illustrating the planar parabolic design of the mirror surfaces and their relative orientation with respect to the PMTs, and the

¹¹ CVS revision Id: aerogel.tex,v 1.4 2003/06/06 21:41:39 gen Exp

¹² Authors: G.J. Lolos <mailto:gjlolos@jlab.org>

orientation of the counter relative to the central axis of the spectrometers.

The close spacing of the μ -metal shields, which is also shown in the photograph of figure 5.19, creates dielectric breakdown problems. The μ -metal shields are at cathode potential (-2950 V) to avoid the capacitive discharge from a grounded μ -metal shield to the glass of the photocathode, which would contribute to the noise level in the PMT, and adversely affect their performance at high operating voltages. This necessitates extra precautions, in order to avoid dielectric breakdown between adjacent shields, and between the shields and the aluminum structure of the counter, which is at ground potential. The solution was to wrap the outer surfaces of the μ -metal shields with a high dielectric value ($12,000\text{ V/mm}$), thin (0.254 mm) Teflon film¹³. In addition, the PMT housings consist of fiberglass-epoxy composites, with added inner and outer skins of 0.0254 mm thick Tedlar¹, with a further combined insulating value of $3,000\text{ V}$. Such a combination of insulating materials eliminates any breakdown or small leakage current induced noise and, at the same time, satisfies all safety requirements.

The final construction of the counter, described in this report, is built around the two sides of the main (PMT) section, each consisting of two pieces of aircraft quality aluminum alloy, with stiffening aluminum rods formed integrally on the top and bottom. The openings for the PMT housings were machined on these structures using CNC milling machines to keep tolerances to fine levels. The double walled structure, on both sides of the enclosure, further increases the rigidity of the exoskeleton by forming a second “outer” wall on each side, very similar in configuration to the inner one, and attached to the latter with crossbolt braces, as shown in the photograph of figure 5.19. Each end plate is made out of the same aluminum alloy as the side walls, and also incorporates stiffening lips folded integrally to each plate, one at the top and one at the bottom. Each end plate has been provided with inlet and outlet gasline connections, which will be used to fill the counter enclosure with dry CO_2 gas to protect the silica aerogel from water vapour absorption. figures 5.19 and 5.20 show the bottom (tray) sections, and main plus upper (mirror) sections, respectively. The main (middle or PMT) section, in figure 5.20, contains the PMTs and provides the strength and rigidity for the whole counter. The one piece aluminum end plates are also shown in both photographs.

All internal surfaces of the detector, except the planar parabolic mirrors, themselves, are lined with aluminized mylar¹⁴ to increase the overall reflectivity of the counter. The mirrors are made in $45 \times 20.5\text{ cm}^2$ moulded surfaces, formed in one rigid structure. The rigidity is provided by two layers of carbon fiber epoxy composite backing, with a combined thickness of 0.28 mm , and a single sheet of mylar with thickness 0.127 mm . The special mylar material was obtained from exposed negative film used in the cartographic industry, and is of high smoothness and uniformity. One side was aluminized at CERN, while the other side remains in its exposed negative (black) state, further adding to the successive light penetration barriers into the enclosure. A representative reflectivity curve, as a function of λ for these mirrors, is shown in figure 5.21.

The upper section of the counter containing the mirrors is mounted on its own

¹³DuPont Canada Inc., Box 2200, Streetsville, Mississauga, ON L5M 2H3, Canada.

¹⁴National Metalizing, P.O. Box 5202, Princeton, NJ 08540, USA.

aluminum subframe, which is bolted to the main frame that houses the PMTs. The upper section, on its own, is shown in the photograph of figure 5.22, while its configuration when mounted on the main section is shown in figure 5.19. The light and gas sealing action is provided by continuous twin parallel rubber strips along the joint area, and by Tedlar film of 0.025 mm thickness covering the top of the outer planar parabolic area.

The third major component of the counter consists of a removable tray where the silica aerogel is placed. The tray occupies the bottom part of the counter and has inside dimensions of $195 \times 41 \text{ cm}^2$ where the SiO_2 silica aerogel is placed. It is formed by a frame with twin aluminum panels, which, in turn, secure the removable frame strung with fishing line in a criss-cross pattern to hold the aerogel panels in place. This “fishnet” frame is secured by screws and is easily removed without disturbing the aerogel panels or requiring restringing. The bottom of the tray is formed out of a single layer of carbon fiber epoxy skin (0.127 mm thick) and a layer of aluminized mylar of equal thickness. Externally, it is covered by a single layer of Tedlar film to assure integrity from light penetration; further environmental isolation is provided by two parallel strips of rubber gasket seals enclosing the circumference of the tray and containing the feed-through spacers for the retaining bolts. The tray is equipped with SMA-type fiber optic feed through connectors for the gain and timing monitor system, which utilizes fiber optic cables. Each fiber illuminates two adjacent PMTs, except the last PMT on either side (13T and 13B in figure 5.17), which have their own dedicated fiber. The light is generated in a gas plasma discharge unit¹⁵ and duplicates the spectrum expected from Čerenkov radiation. In addition, the fibers terminate beneath the silica aerogel, thus, the light reaching the PMTs will have the absorption characteristics of real Čerenkov light produced in the aerogel radiator.

Due to the nature of Cherenkov detectors, where few photoelectrons (PEs) are emitted by the photocathodes in the PMTs, any extraneous light entering the enclosure is very troublesome. As a result of the small number of PEs expected, the PMTs operate either near to, or at, maximum high voltage, and, thus, at maximum gain. As such, they can suffer damage if a sudden light leak develops. In testing, we verified the extreme sensitivity to minute light leaks, even across the whole length of the structure, because of the mirrored surfaces inside the enclosure. With 26 PMTs operating at maximum gain, and viewing, effectively, a giant mirror, sealing the enclosure against single photon penetration requires extra care during initial testing and operations.

The PMTs chosen for the counter were Burle model number 8854, 127 mm photocathode diameter¹⁶. The PMT amplification electronics have been described in Refs. [16, 17]. The dynode chain incorporated a 600 k Ω resistance between the cathode and first dynode, instead of the nominal 300 k Ω . This generates a $V_{dyn} = 885 \text{ V}$ across the cathode to dynode gap, thus, increasing the photoelectron collection efficiency and peak to valley (P/V) ratio. This modification has been proven successful in increasing the PE collection efficiency and the single PE resolution. The dynode amplification chain also incorporates a 11 M Ω resistor in series with the μ -metal shield to eliminate the possibility

¹⁵Optitron Inc. 23206 S. Normandie Ave. #8, Torrance, CA 90502, USA.

¹⁶Burle Industries Inc., 1000 New Holland Ave., Lancaster, PA 17601, USA.

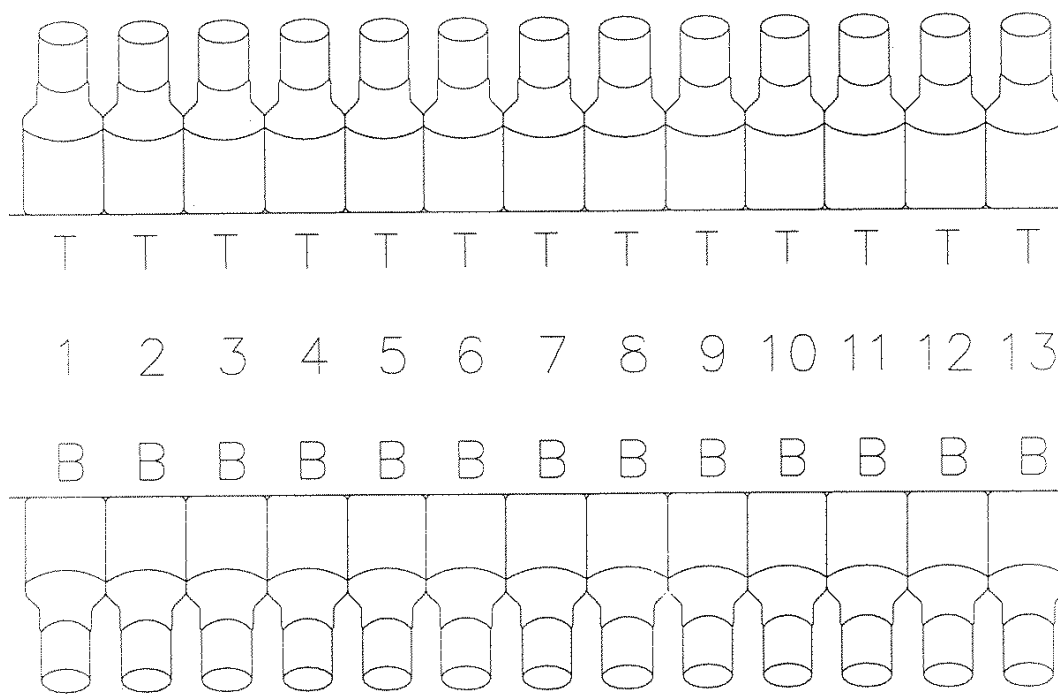


FIG. 1

Figure 5.17: Schematic diagram of the aerogel Čerenkov counter as viewed by the incoming particles. The numbers indicate the sections, 1 to 13, in the counter. Each section is viewed by two PMTs, one on the top (T) and one in the bottom (B). The labeling carries no significance other than identifying the PMTs during the testing phase, as described in the text.

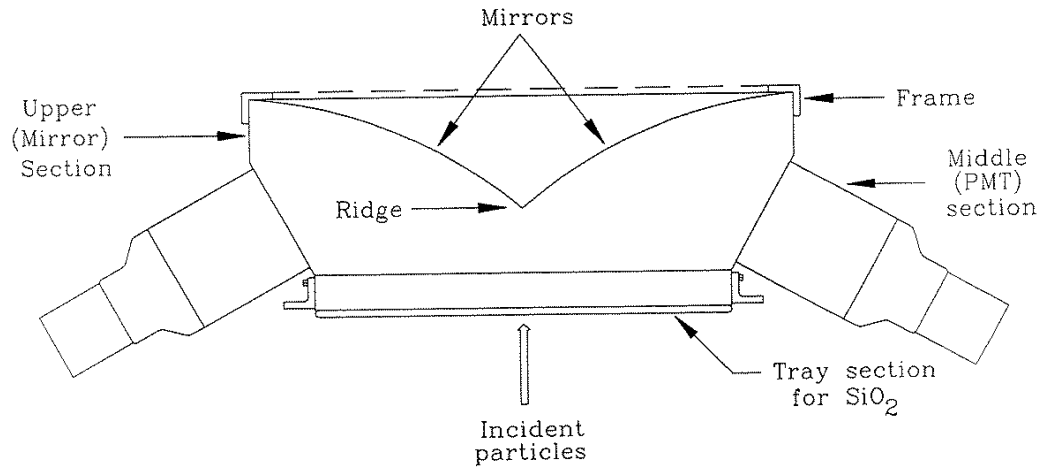


FIG. 2

Figure 5.18: Cross sectional drawing of the counter, along the particle direction, showing the planar parabolic nature of the mirrors and the geometry of the PMTs, as well as the final dimensions. The joint of the two mirror surfaces in the middle of the counter defines the mirror “ridge”.

of electric shock through careless handling; this high impedance also limits the current drawn, in the unlikely event of a complete dielectric breakdown between the shields and the aluminum parts of the detector. A schematic diagram of the electronic amplification chain is shown in figure 5.23.

The operation of the aerogel detector is discussed in Ref. [18].

5.5.2 Responsible Personnel

The following individuals are responsible for aerogel Cherenkov problems.

Serdarević, Maja - x5063

Segal, Jack - x7242

Wojtsekhowski, Bogdan - x7191

5.5.3 Safety Assessment

The PMTs are under high voltage and care is required when handling any components of the counter. As stated earlier on in this report, the insulating material between the μ -metal shield and the aluminum exoskeleton far exceeds the operating voltage. In addition, the 11 $M\Omega$ resistor between the μ -metal shield and the HV source, restricts the current flow below the critical 1 mA level. The combination of Tedlar film, plexiglas composites, and injection moulded bases, are all safe to handle but care should be exercised when handling the aluminum parts of the counter or touching the metal back plate of the



1

Figure 5.19: Photograph showing the final arrangement of the double sidewall structure, and the close spacing of the housings for the PMTs. The bottom section of the counter, with the tray and the aluminized mylar reflector lining, is also shown. In this picture, the particles would be incident from the bottom toward the top of the counter. The upper (mirror) section has been removed for clarity.



1

Figure 5.20: Photograph showing the middle (PMT) section with the double sidewall structures and the housings for the PMTs, with the top (mirror) section attached. The tray has been removed, and the white tabs on the mirrors are pieces of tape holding a temporary protective film in place to prevent damage to the mirror surfaces during transportation. In this figure, the particles would be incident from the top toward the bottom of the picture.

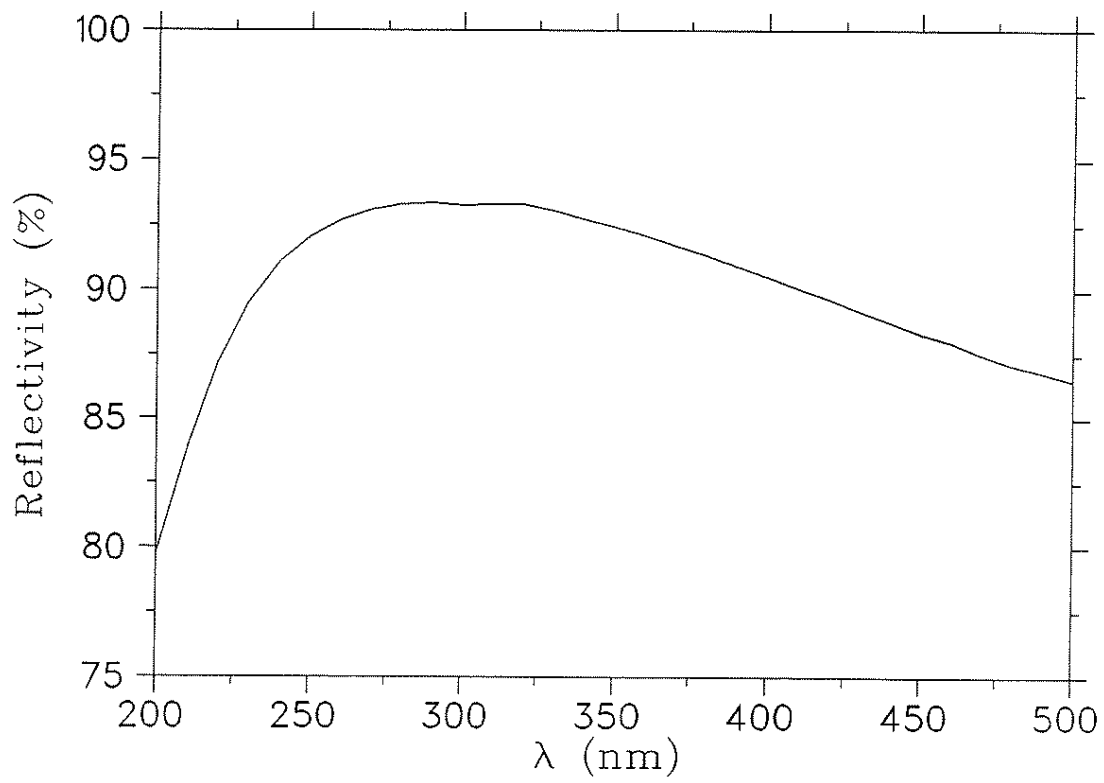


FIG. 3

Figure 5.21: Typical reflectivity curve of a mirror as a function of the wavelength, λ , of the incident light.

1

Figure 5.22: A photograph showing the upper (mirror) section with the planar parabolic mirrors. The mirror surface is protected by a vinyl film in this picture. The mirror “ridge” separating the counter into two halves is clearly seen. This section fits over the open top of the counter in Fig. 5.19.



1

Figure 5.23: Schematic diagram of the electronic amplification chain. The total resistance of $600\text{ k}\Omega$ between the cathode and the first dynode is shown as three $200\text{ k}\Omega$ resistors for sake of clarity. In the actual PC boards, the arrangement is of six resistors of $100\text{ k}\Omega$ each, in order to keep the voltage across each resistor low and avoid surface discharge between the closely packed resistors.

base. It is strongly recommended to ground the aluminum exoskeleton of the counter, at several spots, to a common ground with the HV and signal cable ground. This will further enhance safety and eliminate potential ground loops in the unlikely event of a slow, and otherwise difficult to diagnose, dielectric breakdown from the μ -metal shield to the aluminum structure or the aluminized mylar in the interior.

5.5.4 Operating Procedure

Operating Voltage

The operating voltage on the PMTs is -2,950 V. This is a near maximum rated voltage and it has been shown to combine high efficiency, good P/V ratio, and long PMT life. The overall gain of the PMT is not maximum, as is measured by BURLE, since the dynode chain of the 13 dynodes (2nd dynode to 14th dynode) is kept at -2,600 V equivalent with the original 300 $k\Omega$ resistor value between Cathode and 1st dynode. However, the gain is more than sufficient to separate the one PE from the pedestal of all ADCs we have used so far. It should not be necessary to increase the voltage above the recommended one.

5.5.5 Handling Considerations

It is generally not advised to open up the counter if the persons involved are not thoroughly familiar with the assembly and specific component function. Routine operation does not require any hands on modifications to the detector, as long as the following operating principles are followed:

Installation and Removal of PMTs A replacement of a PMT or repairs of the electronic amplification chain can be accomplished by removal of that specific PMT-Base combination. Turn the HV off on all PMTs and remove the rubber hood covering the base and housing interface region. Now remove the three small screws attaching the base to the integral housing. Note that the base can only be secured to the housing in one specific orientation.

Carefully slide out the base with the PMT and μ -metal shield mounted as one unit. Remove the elastomeric ring positioned between the PMT and the μ -metal shield. Loosen the nut securing the μ -metal shield to the base and carefully apply upward force on the shield while someone else is holding onto the base. This will remove the PMT and the μ -metal shield from the socket and base, respectively.

Replacement of the PMT requires experience because it has to be done with the μ -metal shield installed in, but not secured to, the base. The PMT pins need to be aligned with the socket pins in a specific geometry, thus, the insertion has to be done by feel and experience. Once the PMT is inserted in the socket, the μ -metal shield is secured the base with the nut. Make sure the shield protrudes past the photocathode as much as the tapered design allows. Carefully insert the elastomeric ring between the PMT rim and the μ -metal shield. This ring supports the PMT and prevents it from sliding out of

Table 5.3: The number of photoelectrons detected as a function of PMT and incident beam location in the end plate proximity configuration. $\Sigma^6 P.E.$ and $\Sigma^{26} P.E.$ denotes the measured total number of photoelectrons from six PMTS and the expected total from 26 PMTs, respectively. The incident electron beam location (hit position) is represented by $[\times]$.

PMT Location and Number of Photoelectrons			
1B $[\times]$	4.0	1T	0.2
2B	0.8	2T	0.3
3B	0.6	3T	0.1
$\Sigma^6 P.E.$	6.0	$\Sigma^{26} P.E.$	7.5

PMT Location and Number of Photoelectrons			
5B	0.5		
6B	1.0	6T	0.1
7B $[\times]$	3.5	7T	0.2
8B	1.0	8T	0.1
9B	0.5		

Table 5.4: As in table 5.3, but for the center hit location configuration.

the pins during movement; it also helps seal the interior of the counter from the outside environment and reduces CO_2 leakage rate. Reverse the process for installation.

Installation and Removal of the SiO_2 Tray **PLEASE NOTE:** The SiO_2 aerogel panels are extremely fragile and sensitive to water and chemical vapour. Do not handle with bare hands, use clean cotton, or other fabric type, gloves instead. Surgical gloves often are contaminated with lubricants and are not suitable for this purpose.

The tray is secured to the main section by hex bolts. Removal of the bolts results in the straightforward removal of the tray. There is minimum clearance between the tray walls and the main section; as a result, the tray has to be removed and installed in a uniform translation with respect to the main body. The frame supporting the fish net (or tennis racket) can be removed from the tray proper by removal of the two small screws in the middle of the tray walls and a tool (hook) is provided for this operation. The SiO_2 aerogel panels can now be removed or replaced. Reverse the procedure for installation. The securing bolts do not need to be tightened very much and, although spacers are inserted between the rubber strips to prevent damage, care and common sense should be exercised. Light and gas sealing is provided by the rubber strips NOT by brute force.

WARNING: After each removal of any components of the counter, check for light leaks before turning the HV on at operating values. Even a small light leak can destroy the PMTs if they are at -2,950 V! Check for light leaks with lights out, using a small portable light, and reduced voltage around -2,000 V.

5.6 The Focal Plane Polarimeter ^{17 18}

5.6.1 Overview

The focal plane polarimeter measures the polarization of protons in the hadron spectrometer detector stack. When the protons pass through a carbon analyzer, the nuclear spin-orbit force leads to an azimuthal asymmetry in scattering from carbon nuclei, if the protons are polarized. The particle trajectories, in particular the scattering angles in the carbon, are determined by pairs of front and rear straw chambers, a type of drift chamber.

As shown in Figure 5.24, the front straw chambers are separated by about 114 cm, and are located before and after the gas Cerenkov detector. The second chamber is followed by scintillator 2, which is in turn followed by the polarimeter carbon analyzer. The rear chambers, chambers 3 and 4, are separated by 38 cm and are immediately behind the carbon analyzer.

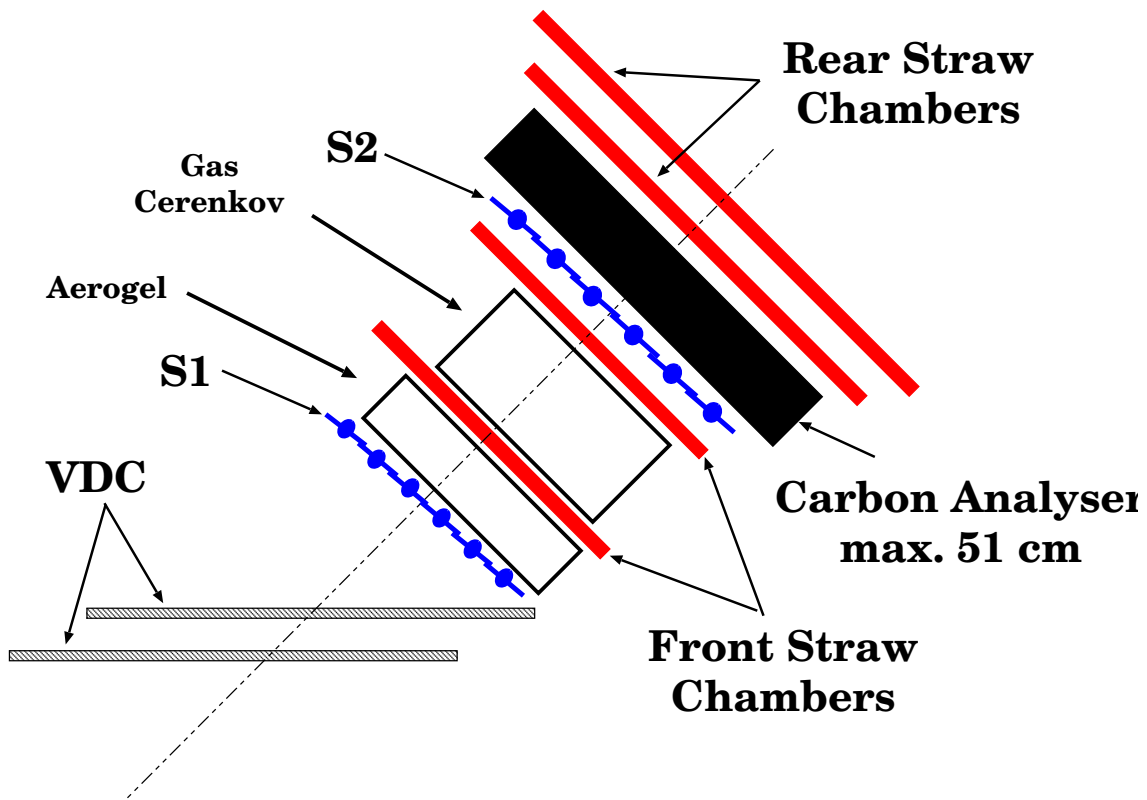


Figure 5.24: Schematic of the hadron detector stack.

The carbon analyzer consists of 5 carbon blocks. Each block is split in the middle

¹⁷ CVS revision Id: fpp.tex,v 1.3 2003/06/06 17:00:27 gen Exp

¹⁸ Authors: Dr.No <mailto:????@jlab.org>

so that it may be moved into or out of the proton paths, so that the total thickness of scattering carbon may be adjusted. The block thicknesses, from front to rear, are 9" (22.9cm), 6" (15.2cm), 3" (7.6cm), 1.5" (3.8cm), and 0.75" (1.9cm). The block positions are controlled through EPICS; the controls may be reached through the Hall A / hadron spectrometer / detectors menus. Particles passing through the carbon analyzer can be absorbed in it.

The straw chamber planes are designated as X, U, and V planes. The central ray defines the z axis. X wires measure position along the dispersive direction. The UV coordinate system is created by a 45 degree rotation in the transverse plane of the XY coordinate system, with +U between the +X and +Y axes, and +V between the +Y and -X axes.

The straw chamber operation is described in the following paragraphs.

When a charged particle passes through the chamber in typical Jefferson Lab operating conditions, there will be about 30 primary ionizations of gas molecules. Positive high voltage of about 1.8 - 1.9 kV is applied to the wire in the center of each straw. Electrons from the ionizations drift towards the wire. When the electrons get within about 100 μ of the wire, the gain in energy between collisions with gas molecules is sufficient that gas molecules are further ionized in collisions. This leads to an *avalanche*, and a gain of about 10^5 per primary ionization under the conditions in which the FPP is run.

The movement of the positive and negative ions leads to a voltage drop on the wire, or equivalently to a negative analog signal. The analog signal is about 20 ns long, with a (negative) peak current of about 40 μ A, and propagates towards each end of the straw. At one end of each straw is a board that supplies high voltage (see Figure 5.25); impedance matching on this board, with a 1500 pF capacitor and a 370 Ω resistor, reduces reflection of the signal.

The other end of each straw is connected to a readout board, that amplifies, discriminates, and multiplexes the input signals – (see Figures 5.26 and 5.27). At the readout end, the signal is “coupled to ground” through a 1500 pF capacitor followed by 310 + 50 Ω resistors. In parallel with the 50 Ω resistor are diodes to limit the signal size, preventing damage to the readout board circuitry. An amplifier samples the signal over the 50 Ω resistor. The amp gain is about -10 mV/ μ A, resulting in a +400 mV signal to a comparator. A threshold voltage input to the readout board is put over a voltage divider consisting of 1500 + 10 Ω resistors. For the typical 4 V threshold applied to the board, the comparator puts out a logical pulse when the 400 mV (peak) signal rises above the 4 V / 151 = 26 mV threshold. One-shots are then used to fix the width of the logical pulse for each channel – the one-shot width is fine tuned by the use of high precision resistors in an RC circuit; these resistors are mounted in sockets so as to be easily replaced if the need arises. An OR circuit then combines eight individual straw outputs into a single electronics channel.

Internally, within the Faraday cages, the high voltage is distributed to stacks of high voltage / test pulser boards, through which it is connected to each straw via a 1 M Ω 1/4 watt resistor.

The readout cards require a high-current low-voltage power supply and a low-current

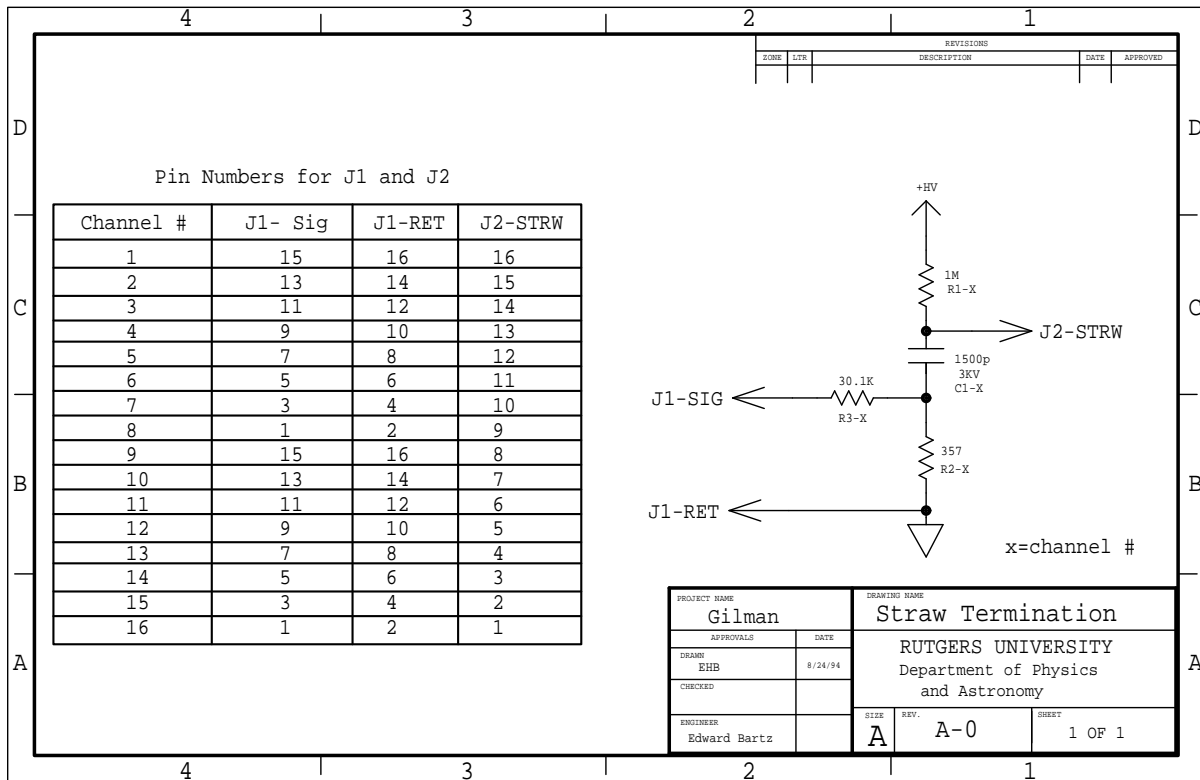


Figure 5.25: Circuit diagram for the high voltage / termination board.

low-voltage power supply for a threshold level. The readout electronics are mounted on the chamber, shielded within Faraday cages. The high-current power supplies were built by the Rutgers University Department of Physics & Astronomy Electronics Shop. These supplies are set to provide sufficient current at ± 5 V for the boards to which they are hooked up. No adjustments, except for turning the supplies on / off, should be needed in normal operation. There are voltage setting, current limiting, and overvoltage protection potentiometers within the boxes; adjustment information is given in the FPP logbooks. The low current supplies are *Hewlett-Packard* 6111A supplies. The 6111As can provide up to 1 A for voltage from 0 to 20 V. The supplies are currently hooked up through the rear panel to a DAC in the data acquisition panel; front panel controls on the supplies are disabled, except for the on/off switch. The voltage is controlled through an EPICS FPP threshold window, that is accessed through the Hall A / hadron spectrometer / detectors menus. The high-current supplies are not computer controlled. All supplies are mounted in the detector stack.

The multiplexed logical signals from the chambers have amplitudes smaller than ECL levels, to prevent noise at the chamber. These signals are fed to level shifter boards (see Figure 5.28), located in the FPP rack on the lower electronics level of the detector stack, on the beam right side. A high-current ± 5 V power supply for the level shifter

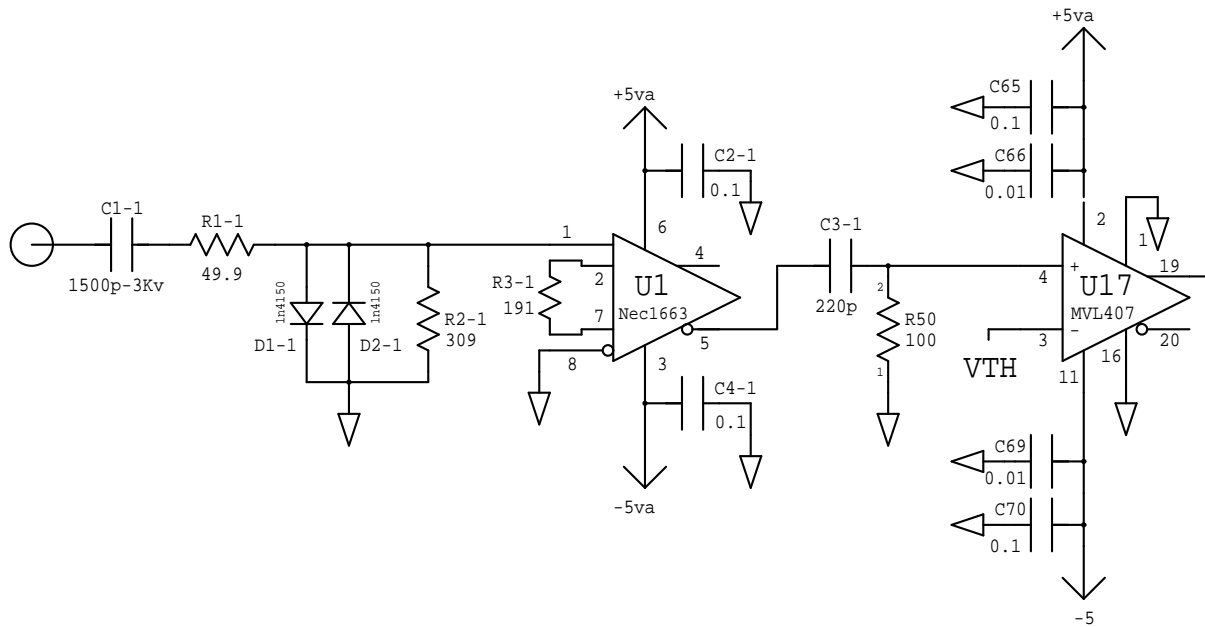


Figure 5.26: Circuit diagram for the amplifier / discriminator section of the readout board.

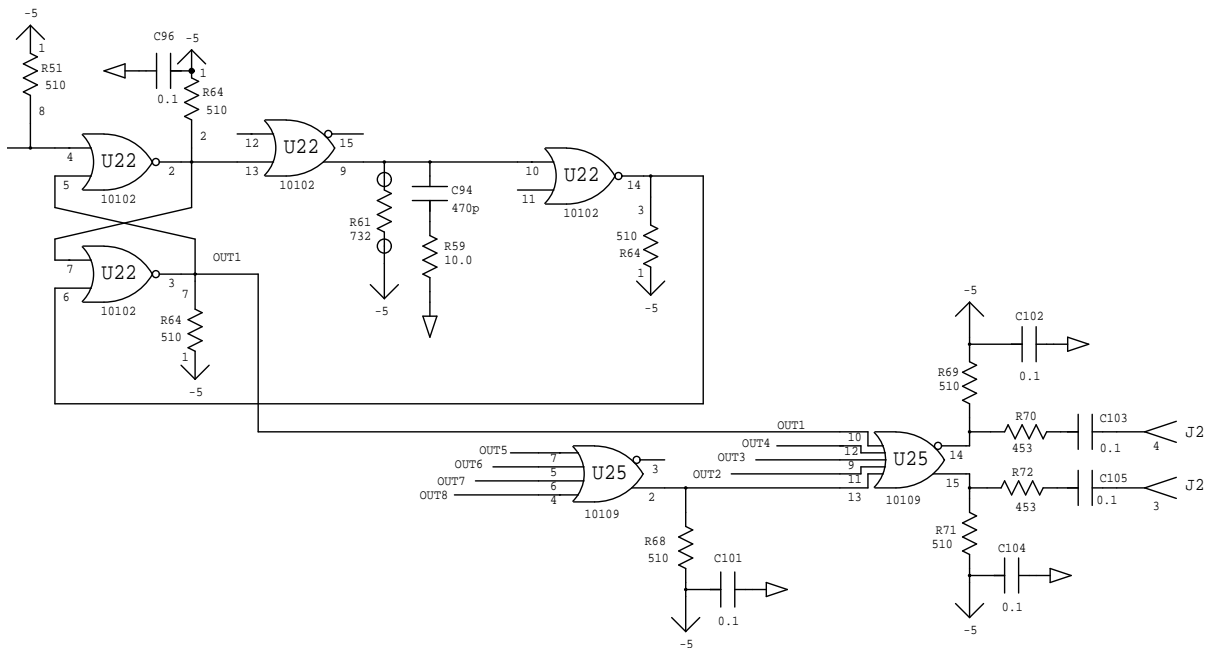


Figure 5.27: Circuit diagram for the logical / multiplexing section of the readout board.

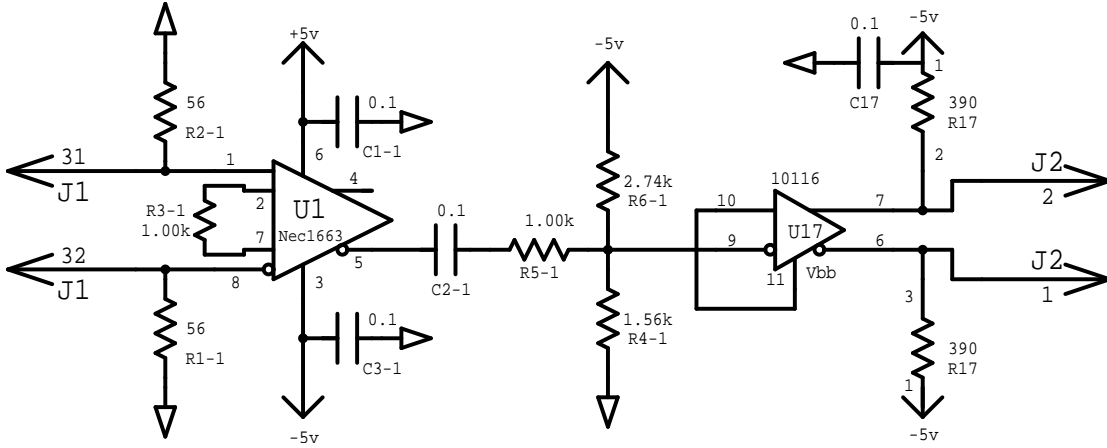


Figure 5.28: Circuit diagram for the level shifter / receiver board.

boards is located at the bottom of the same rack. The boards convert the signals to ECL standard levels. The level shifter outputs are connected to the starts of *LeCroy* Model 1877 FASTBUS TDCs, located in the lower electronics level on the beam left side. The TDCs measure both leading and trailing edge times to allow demultiplexing. The TDCs are subsequently stopped by the overall event trigger, and are read out by the *CODA* acquisition software. The data are histogrammed online by the *DHIST* software. In-depth offline data analysis requires the *ESPACE* software.

The chamber gas is presently a combination of argon and ethane, about 63% and 37% by weight. The Hall A gas shed is outside next to the entrance of the Hall A truck ramp. Gas is routed from the Hall A gas shed mixing system to the gas panel located on the lower electronics level of the space frame, and subsequently to the FPP chambers. The gas system is shared with the VDCs. A detailed description of the system has been written by Howard Fenker¹⁹.

In addition, the chambers are outfitted with a test pulser capability. A pulse is introduced into an 8 channel (16 wire) twisted pair cable on each chamber, which connects to the high voltage boards, at the opposite ends of each straw from the readout boards. The pulse is resistively coupled through a 20 k Ω resistor to the ground leg of a 1500 pF capacitor, and thence into the straws. After propagating through the straw, the pulse enters the readout board. A pulse of about 1 V amplitude in the twisted pair cable is sufficient to provide a few mV signal into the readout boards, resulting in a logical output signal. The system may be used to test the functionality of each readout channel and / or the continuity of the high voltage wire in each straw. The system currently is only implemented for manual operation, except that data may be read out through CODA. This procedure requires some familiarity with trigger logic and setup, should only be done by experts, and is not documented here.

¹⁹http://www.jlab.org/Hall-A/document/HAWGS/HAWGS_OpMan.html

5.6.2 Operating Procedure

Gas Flow Operating Procedures The chamber gas is mixed 63%-37% (by weight) Ar ethane. The gas is mixed in the Hall A gas shed which is located next to the entrance to the Hall A truck ramp. One needs key #8, which is located in a key box in the Hall A counting house, to get inside the shed where the gas mixing is done. The argon and ethane bottles which feed the gas mixing system are located outside the shed and can be exchanged when they are empty. The mixed gas is sent down into Hall A and to each of the detector huts. There are two each of argon and ethane bottles connected to the gas system and a Matheson 8590 controller switches between the two bottles when the gas pressure in the bottle drops below a certain level. At this point the one bottle can be replaced while the other is being used. The procedure for changing gas bottles is outlined below:

1. Warning: High pressure gas bottles contain significant stored energy and are potentially hazardous. Handling of gas bottles should be done only by qualified, trained personnel.
2. For smoothest operation, used gas bottles should be replaced before their internal pressure drops below the desired regulator output pressure.
3. Two possible cases exist in which a gas bottle needs to be replaced: only one empty gas bottle on a system or both bottles empty on a gas system.
4. For case 1 the sequence of steps is as follows:
 - (a) Check in the Hall A Gas Shed. If all bottles have sufficient pressure each of the Matheson 8590 controllers will have one green "RUN" LED lit and one yellow "READY" LED lit. A red "EMPTY" LED lit indicates a bottle with low pressure, the corresponding bottle needs to be replaced. If a red "EMPTY" LED is lit the central "ALARM" LED should also show red. Nothing further needs to be done here; go outside to the Gas Bottle Pad.
 - (b) Visually verify that the corresponding pressure gauge on the flex line is showing a low pressure. A low pressure is not necessarily zero. Close the bottle valve for the empty bottle.
 - (c) Disconnect the empty bottle from the high-pressure flex-line. The in-line check-valves will prevent gas escaping from the manifold. Replace the bottle's cap, and move the empty bottle to the EMPTIES storage rack. Note that ethane bottle fittings, type CGA-350, have left-handed threads.
 - (d) Place a full bottle of gas in the on-line rack, remove the bottle cap, and connect the bottle to the flex-line.
 - (e) Open the new bottle's valve, check for leaks at the bottle fitting. The corresponding pressure gauge should now read full bottle pressure.

- (f) The ALARM state of the Matheson 8590 controller should have automatically reset. Check inside the Hall A Gas Shed. Each controller should show a green "RUN" and yellow "READY" LED lit. If not, re-check the installation of the gas bottle.
5. For case 2 the sequence of steps is as follows:
- (a) Check in the Hall A Gas Shed. If all bottles have sufficient pressure each of the Matheson 8590 controllers will have one green "RUN" LED lit and one yellow "READY" LED lit. If a Matheson 8590 controller shows two red "EMPTY" LEDs lit and the central red "ALARM" LED lit, both bottles of the corresponding manifold need to be replaced. Nothing further needs to be done here, go outside to the Gas Bottle Pad.
 - (b) Follow steps 2. through 5., as detailed immediately above, for both bottles.
 - (c) The ALARM state of the Matheson 8590 controller should have automatically reset. Check inside the Hall A Gas Shed. Each controller should show two yellow "READY" LEDs lit. If not, re-check the installation of the gas bottle. Press either of the two buttons labeled "LEFT BANK" and "RIGHT BANK". The lit LED above the button you pressed will change from yellow "READY" to green "RUN". You will most likely need to reset the Low Supply Pressure shutdown at this point.

The four FPP straw chambers are connected in parallel to the gas system. (see Figure 5.29).

(The FPP chambers are also in parallel with the VDC chambers.) All gas connections are made using POLYFLOTM tubing and TJNAF-specified connectors. The chamber volumes range from approximately 120 to 220 ℓ . Gas pressure in the chambers is typically a few Torr above atmospheric pressure. The gas flow through the chambers may be independently varied and is typically set to 7 ℓ /hr, leading to a replacement of the chamber volumes about every 15 - 30 hours. Gas is exhausted from the FPP chambers through a bubbler containing < 1 mm of mineral oil. A typical chamber leakage rate at this flow rate is 25 - 50 %. The flow rate of 7 ℓ /hr when combined with the leak rate of ≤ 3 ℓ /hr results in a complete exchange of gas in the chambers roughly every 1 - 2 days. At this level of consumption, a full gas bottle connected to the FPP system lasts approximately 10 days. When a bottle is nearing empty ($\approx 90\%$), it should be changed since there may be heavy contaminants in the gas. Gas bottles may only be changed by authorized personnel.

Gas-handling Procedures

1. Typically gas is continually flowing though the chambers. If at all possible, gas flow should be continuously maintained, even in no-beam time periods. This avoids time loss to reconditioning and maintains the desirable steady-state operating condition. If the chambers are not being used in an experiment, the flowmeters for the front

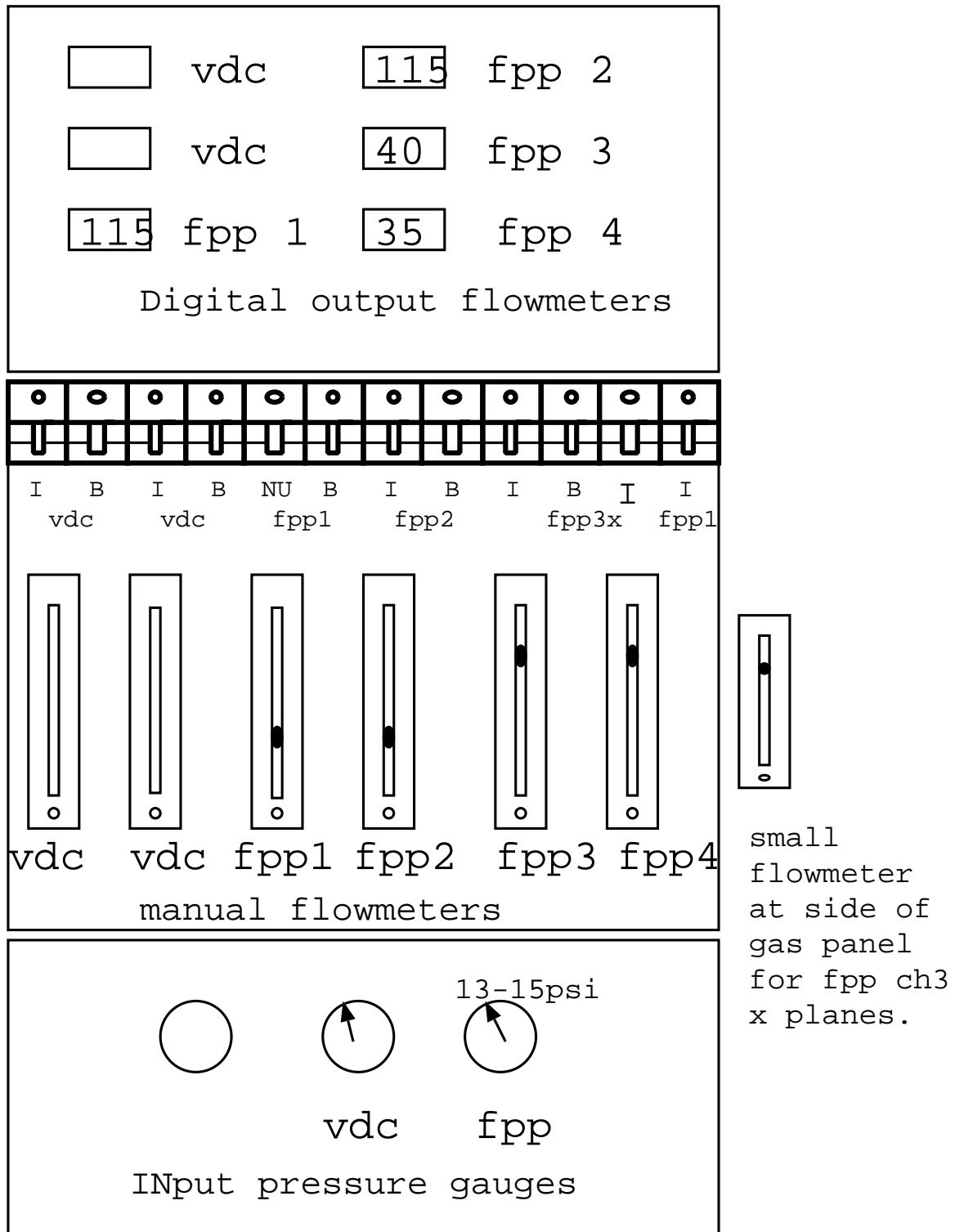


Figure 5.29: Drawing of the gas panel on the hadron detector stack.

chambers are set to 20 and the flowmeters for the rear chambers are set to 60. When the chambers are used in an experiment the standard setting for the front chambers is 40 and for the rear chambers it is 105.

2. Gas pressure at the gas panel on the detector stack should be in the range 13 - 15 psi. With the large leakage rate of the FPP chambers, we typically run at near the limit of the capacity of the gas mixer to supply the gas flow demanded by the FPP and VDC chambers. Therefore it is possible to demand too much flow rate from the mixer. If the gas pressure drops below 13 psi drop the flow to the FPP chambers and contact Jack Segal or Howard Fenker to determine the cause and remedy for the situation.

The status of the gas handling system should be monitored carefully as well as logged at least once per 8-hour shift. Any substantial deviation from the median parameters indicates a change in the operational parameters of the FPP and should be immediately investigated.

Power Supplies and Electronics Procedures The power supplies and readout electronics associated with the FPP are a mixture of commercially purchased equipment and equipment designed and/or assembled with the Rutgers University Department of Physics & Astronomy Electronics Shop. The reader is directed towards the manuals made available by the manufacturer for the detailed information not provided here for the commercial equipment. For the Rutgers constructed equipment, further documentation is available on the web page²⁰.

and through FPP notebooks (try for example contacting R. Gilman for notebooks maintained by Rutgers, CEBAF Center, phone 757.269.7011).

The LeCroy 1458 HV control crate houses the Lecroy 1469P modules which control the HV for the FPP chambers. The 1469P has 3 master HV channels and each master HV channel controls eight slave channels. In slot 7 of the 1458 is the 1469P module which controls chamber 1 and chamber 2. In slot 8 of the 1458 is the 1469P module which controls chamber 3 and chamber 4. The individual slave channels can trip from high current faults or other trip faults, but all eight slave channels must be raised and lowered together by setting the master high voltage. The HV provides +1.8 - 1.9 kV nominal to each of the ≈ 5100 wires in the four FPP straw chambers. The power supply is located in the detector stack at the top of crate 6 in the upper electronics level. This unit is controlled through HAC13. Connections from the power supply to the chambers are made using standard SHV connectors mounted on red RG-59/U HV cable good to 5 kV.

The high-current low-voltage supply boxes were assembled by Rutgers University. They are designed to provide a maximum current of about 1.6 / 0.6 A at -5 / +5 V to each of the 318 readout cards on the four chambers. There are 63 / 63 / 90 / 102 cards on chambers 1 / 2 / 3 / 4. Typical operating currents are about two-thirds of this nominal

²⁰<http://www.jlab.org/~gilman/fpp-homepage.html>

maximum value. The ± 5 V power lines are independently fused to each card. Each of the eight supply boxes contains two or three power supplies, each rated for either 35 or 50 A. There are two power boxes for each chamber. Six boxes are located at the lower rear end of the detector stack. The second boxes for chambers 3 and 4 are located at the top of the detector stack, on an aluminum plate just off the upper electronics level. These power boxes are monitored through EPICS, but turned on/off through front panel switches.

Hewlett-Packard 6111A power supplies are used to provide typically 2 - 3 mA current per readout card. Each of the front and rear chambers have their own power supply. The front chambers thresholds are fused, to limit current drawn in case of a short on the board. The rear chamber cards use a $1.5\text{ k}\Omega$ resistor external to the board to limit current drawn, in case of a short on the board. Board threshold circuitry also has a $1.5\text{ k}\Omega$ to ground which with the external $1.5\text{ k}\Omega$ makes a voltage divider. Therefore, the rear threshold supplies are typically set to a voltage which is a factor of two larger than the front threshold supplies to give the same threshold voltage at the readout board. Initial tests indicate that at least a 1.5 V threshold must be applied to the cards to prevent oscillations - this level will stop oscillations that arise when the voltage applied is reduced to about 1.0 V. In practice it has been found that the front chambers should be operated at 4 V and the rear at 7 V. Efficiency studies show that the chamber threshold could be raised by 50% with minor loss in efficiency. The HP supplies are also mounted in the hadron arm detector stack, on an aluminum panel located beneath the two upper high current supplies.

Each straw wire contains a $25\mu\text{m}$ ϕ , Au-plated tungsten-rhenium wire. The number of wires per plane varies from 176 to 272. Wires are multiplexed 8 wires into one electronics channel, leading to a required 636 TDC channels. In practice a few extra channels are used, so that each 34 wire (16 differential signal channels plus one ground pair) twisted pair cable contains only signals from one of the four chambers. LeCroy 1877 multihit FASTBUS TDCs are used to measure the leading edge time and width of the pulses, to demultiplex the wire hit. Within each group of eight wires, the widths are set to about 25, 45, 35, 55, 90, 65, 105, and 75 ns. The TDCs are located in the upper FASTBUS crate located on the lower electronics level of the spectrometer space frame in the detector hut. The FPP rack, containing level shifter cards, is located opposite the FASTBUS crates on the lower electronics level. It shifts signals sizes from the reduced $\pm 50\text{ mV}$ readout card output levels to ECL standard levels, for input to the TDCs. The connections between the readout cards and the level shifter cards, as well as between the level shifter cards and the TDCs, are made with 16-conductor twisted-pair cables. A wiremap, detailing the cabling, is posted on the side of the FPP rack.

Power-up Procedure

1. Ensure that gas flow has been established in the chambers as outlined in the previous section. If it has not, *STOP RIGHT HERE!* Gas flow must be well-established and steady-state *BEFORE* the HV may be enabled.

2. Ensure that all power supplies as well as the FASTBUS crate are off and the LV, HV, and TDC cables are connected.
3. Turn on the threshold and LV power supplies. Use EPICS to turn the threshold voltages up to correct values, about 4.0 V for front chambers 1 and 2, and 7 V for rear chambers 3 and 4.
4. Use HAC13 to turn up the chamber voltages. Standard values are 1875 V for front and rear chambers. It is probably best to raise the HV in 300V steps. After each step wait for the current to settle below 1 μA , then go up to the next level until 1875V is reached. Peak currents during turn-on should not exceed about 40 μA . A 10 V/s ramp rate leads to a leakage current of several μA . Trip levels should be set to 110 μA both for turning on HV and for normal operation, so that bad spills do not trip the chambers. Current should settle to about a μA or less within a few minutes. If the power supply trips during the ramping procedure, it is possible that you are moving too fast, or that some problem has developed with a chamber. Rezero things and begin the procedure again. *NEVER USE THE AUTO-RESET FUNCTION.* If the power supply trips again, *STOP IMMEDIATELY AND INVESTIGATE. There is probably a problem and expert advice may be needed. Some detailed information, intended for experts debugging hardware problems, is available in the Rutgers web pages.*
5. Check for poor signal connections evidenced by hot wires (wires counting extremely fast) or dead wires (wires with no counts) using the histogramming software and cosmic rays. Be careful: apparent problems may result from bad demultiplexing rather than from poor signal connections. Remake any connections as necessary by first powering down the FASTBUS crate.

If at all possible, the HV and LV power supplies should be left on continuously if and only if gas is available to the chamber. This avoids time loss to reconditioning and maintains the desirable steady-state operating condition.

5.6.3 Carbon Doors

Four of the five doors operate remotely, the fifth needing further testing before it is certified reliable. The doors use the EPICS control system to activate and read back the various components.

Each layer of carbon doors has one relay board. Each board is identical in operation and there is one spare in the event one of them should fail. The global purpose of the relay board is as follows:

1. Turn on the 12V to power to rest of circuit board.
2. Set the polarity on the 90V used to power the motors.
3. Turn the 90V on.

4. Cut off the 90V to a motor if the appropriate limit switch is hit.
5. Read back the status of the limit switches.

The 12V used to power the circuit board runs through this relay and it is activated via an EPICS relay in VME crate 4 (hallasc4). Relay #1 turns on the 90V and it too is activated by an EPICS relay in VME crate 4. Relay #2 switches the polarity of the 90V being fed to the driving motors. When activated it reverses the polarity to the motors and it is controlled by a relay in VME crate 4. Relays #3 and #5 are activated by the inner limit switches of the carbon doors. When these switches are depressed the relay activates and the 90V is cut off. Relays #4 and #6 are activated by the outer limit switches of the carbon doors and like relays #3 and #5 cut off the 90V when activated. Relays #4 and #6 activate when opened rather than when depressed. It would be nice in the future to have relays #3 and #5 also activated by an open limit switch condition and deactivated when the switch is closed. This way the 12V could be off to one of the switches and the doors would stop moving. As it is now, a broken wire/short while the doors are closing could cause the doors to continue moving risking possible damage.

The status of the limit switches is readout via an ADC in VME crate 4. If the switches are closed a -4V is seen at the ADC input. This is effected via a voltage splitter of 3 k Ω - 6 k Ω resistors. The readouts are plugged in via telephone jacks (PJ4, PJ5, PJ6, and PJ7). A temporary fix has been put in place which sends the signals through a capacitor first to block voltage spikes going into the ADC. These voltage spikes caused the ADC to trip off-line which can only be fixed by resetting the VME crate.

The operation of the carbon doors is done via a GUI style control panel. This panel is located under the detector screen of the hadron arm (FPP Carbon Doors). The 3/4" carbon door has been disconnected at the 90V power supply and is not implemented in the software GUI. This door had what may have been some sliding problems. Since it may take a great deal of force to remove this door if it should jam, it will need to be tested so it can be removed easily if it should jam. The normal operating procedure with the GUI is to first make sure all the 90V power is off to each door (Blue switches), then to turn on the 12V power to each door to see where it is located in the stack (in vs. out). If you wish to change the status of a door (in/out) then simply toggle the IN/OUT switch appropriately and turn on the 90V. It takes some time for the doors to move the entire range, so be patient. When the limit switches have been reached the appropriate indicators will light up. You should then turn the 90V off. The important aspect of this procedure is to make sure that you do not change the polarity of the 90V while the doors are moving. This place undue stress on the motors and the power supply as well.

5.6.4 Handling Considerations

The FPP straw chambers are very delicate devices which are absolutely essential to many Hall A physics experiments. Thus, extreme care must be taken whenever they are moved or used. Also, extreme care must be taken that other objects are not moved into them.

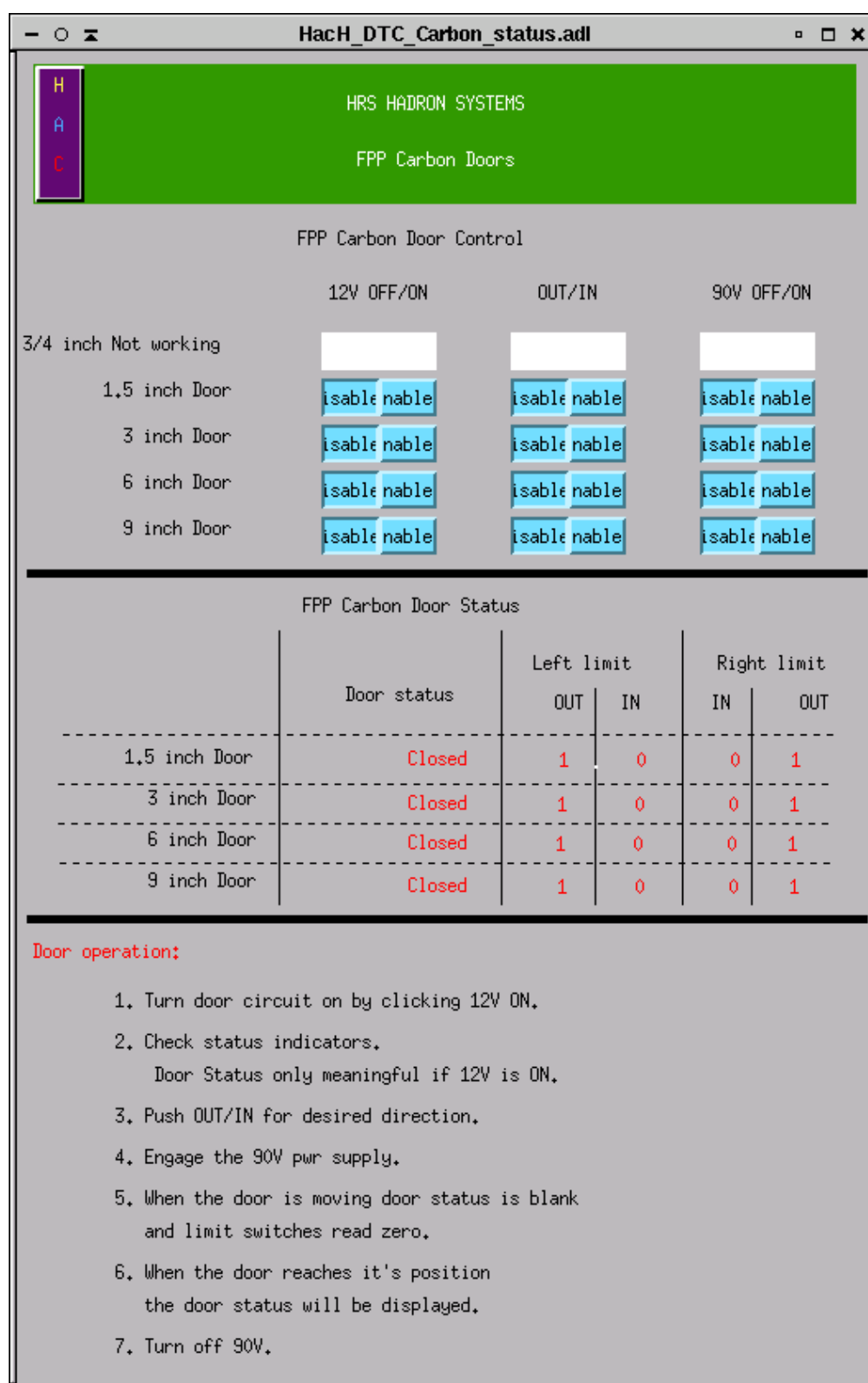


Figure 5.30: EPICS GUI for the carbon doors.

- Before moving a straw chamber, ensure that any protective plates are in position.
- Disconnect and reconnect all TDC, HV, and LV cables with care.
- When initiating gas flow, pay strict attention to the feedback parameters. Straw chambers are not very sensitive to overpressure of perhaps 50 - 100 Torr, but **the straw chambers can be easily destroyed by a few Torr underpressure**.
- Never attempt to apply HV to the chambers until gas flow conditions have reached steady-state.
- As the amount of heat generated by the pre-amp/discriminator cards is substantial, always make sure adequate cooling is provided before attempting to run. This is mostly ensured by making certain that the various cooling holes through the Faraday shields are not covered. The chambers have internally mounted fans where needed, which are powered up along with the readout cards.
- If the leakage current on the high voltage rises linearly with voltage, then a wire has broken and is shorted to ground!

5.6.5 Safety Assessment

The following potential hazards have been clearly identified.

The High Voltage System The LeCroy 1458 HV low current power supply provides a nominal +1.80 kV. Red HV RG-59/U cable good to 5 kV with standard SHV connectors is used to connect the power supply to the chambers. Each HV channel, of the 6 per chamber, typically will draw a few hundred nA.

The Low Voltage System LV power supplies are used for the pre-amp/discriminator/multiplexer cards. Each card requires up to 1.6 A at -5 V and 0.6 A at +5 V, plus a few mA threshold at 4 - 8 V.

High Pressure Gas Bottles The gas used in the chambers is supplied in high pressure (≥ 2000 psi) gas bottles. This confined high pressure gas represents a tremendous (potentially lethal) amount of stored energy.

5.6.6 Responsible Personnel

The following individuals are responsible for chamber problems. Generally, the non Jefferson Lab people are responsible for FPP detector problems, whereas the Jefferson Lab people are responsible for more general data acquisition problems or, e.g., gas / voltage supplies shared with other systems.

Ronald Gilman, Rutgers - x7011, pager 0161

Mark Jones, William & Mary - x5255, pager 849-5045

Charles Perdrisat, William & Mary - 221.3572 or 3522

Xiangdong Jiang, Rutgers, x7011, pager 849-6664

Steffen Strauch, Rutgers, x7011,

Jack Segal, Jefferson Lab - x7242

Bogdan Wojtsekhowski, Jefferson Lab - x7191

5.7 The Hall A Gas System ²¹ ²²

5.7.1 Overview

The Hall A detector gas systems are located in the Hall A Gas Shed alongside of the truck ramp for Hall A. The gas cylinders in use are along the outside of the Gas Shed in a fenced area. There are racks next to the Gas Shed for storage of full gas cylinders. On the other side of the truck ramp there are racks for storage of both full and empty cylinders. Hall A currently uses ethane, argon, ethanol, carbon dioxide, methane, and nitrogen. Details of these systems can be found in the Hall A Gas Systems (HAGS) manual. A copy of the current manual is in Counting Room A and on the Hall A web page.

Four systems are supplied from two cylinders of Coleman grade CO₂. One system is for the gas Cerenkov counters in the HRS detector arrays. One system is for flushing the mirror aerogel Cerenkov counter in the HRS detector arrays. One system is for the gas Cerenkov counters in the (e,p) setup in the beamline. One system is for the FPP straw tube wire chambers. Argon and carbon dioxide for the FPP straw tube wire chambers are mixed inside the Gas Shed.

Three systems are supplied from two cylinders of UHP grade argon. One system is for the VDC wire chambers of both arms. Argon and ethane for the VDC wire chambers are mixed inside the Gas Shed and bubbled through ethyl alcohol. One system is for the FPP straw tube wire chambers. Argon and carbon dioxide for the FPP straw tube wire chambers are mixed inside the Gas Shed. One system is for flushing clean, inert gas through the RICH detector wire chamber.

One system is supplied from two cylinders of Chemically Pure grade ethane. This is for the VDC wire chambers of both arms. Argon and ethane for the VDC wire chambers are mixed inside the Gas Shed and bubbled through ethyl alcohol.

Two systems are supplied from two cylinders of UHP grade nitrogen. One system is used to provide pressurized gas for the automatic cylinder switch-overs in the systems. One system is used to flush impurities from the RICH detector freon reservoir.

One system is supplied from two cylinders of UHP grade methane. The system is for the wire chamber of the RICH detector.

Maintenance of the gas systems is routinely performed by the Hall A technical staff. Shift personnel are not expected to be responsible for maintaining the detector gas systems. Unexpected maintenance requirements should be handled by contacting

Jack(John) Segal - pager and phone are both extension 7242

Hall A Technician on call

²¹ CVS revision Id: gas.tex,v 1.4 2003/11/14 18:54:53 segal Exp

²² Authors: J.Segal <mailto:segal@jlab.org>

5.7.2 Gas Alarms

In Counting Room A there are two alarm panels associated with the gas systems for the detectors. They are located on the far left end of the control console, mounted one above the other. The upper panel is a Gas Master flammable gas monitoring system. The lower panel is a gas systems status indicator. The Gas Master system will go into alarm if elevated levels of flammable gas are present in either of the Detector Shielding Huts or the Gas Shed. The gas systems status will alarm if any of a number of faults are detected in the Hall A Wire-chamber Gas System. The LED for the specific fault will turn red to indicate which fault caused the alarm.

Response to an alarm should be to contact either of the personnel listed above.

5.8 HRS Gas Supply System for Wire Detectors ²³

²⁴

5.8.1 Overview

The detector systems in both HRS's (FPP and VDC) are expected to use a mixture of Argon and Ethane in roughly equal proportions, plus about 1% ethanol. The Argon and Ethane are supplied from high-pressure gas bottles. They are combined in the desired proportion by a mixing system and this mixture is passed through a bath of isopropyl alcohol which is maintained at a fixed temperature. See Figure 5.31 for a schematic diagram of the gas supply / mixing system.

The gas mixture is delivered to gas distribution racks in the Hadron Spectrometer and the Electron Spectrometer. The transmission lines and the distribution plumbing have been designed as if the FPPs and VDCs were actually independent systems using different gas mixtures. This design was chosen in order to ease the expected transition to such a system in the future. Also supplied is a source of purge gas, currently pure argon. The distribution racks provide, for each detector, selection of either operating gas or purge gas, flow control and metering, overpressure relief to protect the detector components, exhaust flow measurement, and backflow prevention.

Bulk Gas Supply

The bulk gas supply consists of two bottles each of Argon, Ethane, and Carbon-Dioxide. Except for fittings which vary by type of gas the three supplies have identical plumbing. One bottle of each gas will be on-line during system operation while the second bottle serves as a ready reserve (connected to the manifold, but valved off). The two bottles are connected through check valves and manual valves to a high-pressure manifold. The pressure in this manifold is sensed by a pressure transducer whose signal is available to the slow-controls computer for monitoring. The pressure is also indicated locally by a mechanical pressure gauge attached to a two-stage regulator. A pressure regulator for each type of gas reduces the pressure to approximately 45 psig. This is the pressure at which gas is supplied to the gas shed. It may be monitored by the outlet pressure gauges (PG-021, -022, -023) on the pressure regulators and, inside the gas shed, on gauges PG-131, -132, -133. Prior to entering the shed the gas passes through manual valves (MV-031, -032, -033), Excess Flow Valves (XF-041, -042, -043), and Solenoid Valves (AV-051, -052, -053).

The Excess Flow Valves automatically close if the flow rate exceeds about 4 slpm at 45 psig. These valves must be manually reset after they trip. Refer to the section *Resetting a closed Excess Flow Valve* for this procedure. The solenoid valves are electrically operated (24 VDC) normally-closed valves. Power must be supplied to the solenoids in order for gas to flow. Valve power is supplied, when interlock conditions are satisfied,

²³ CVS revision Id: gas-full.tex,v 1.2 2003/06/06 21:41:39 gen Exp

²⁴ Authors: J.Segal <mailto:segal@jlab.org>

by the Gas Interlock System. Note that one of the required interlock conditions is that there be ample gas pressure *downstream* of the solenoid valves. System operators must use the manual **”Low Pressure Override”** pushbutton on the interlock panel (in the mixing room) in order to initially bring up the 45 psig supply pressure. The pushbutton circuit automatically re-arms after ample pressure is detected by the pressure switches (PS-111, -112, -113). These switches are located immediately above gauges PG-131, -132, and -133. Just below these gauges are overpressure relief valves (RV-121, -122, -123) which have been set to release if the supply pressure exceeds about 60 psig. After passing through check valves which prevent backstreaming the three gas supplies enter the mixing system.

5.8.2 Gas Mixing Station

The gas mixing system works by metering three gas supplies into a common mixing tank. The mixture is then bubbled through alcohol in a tank within a small refrigerator which has been modified for safe operation in a flammable gas system. Because the gas *flow*, not the pressure, is regulated by the metering system, pressure switches have been installed to monitor the mixer outlet pressure and provide feedback to the flow-control system. The mixing, bubbling, and pressure control systems are all built into the same relay rack. They are collectively referred to as the Gas Mixing Station. A flow diagram is shown in Figure5.31

Mass Flow Control System

The flow rate of each component gas is controlled by a mass flow controller which delivers a constant mass of gas per unit time. (Tylan General model FC-280AV) The mass flow is independent of pressure, although a minimum differential pressure across the controller is required for proper operation. The valves are factory-calibrated for Nitrogen (N_2). The system controlling them is field-programmed to compensate for different gasses. Flow channel 1, currently assigned for CO_2 , has a mass flow controller calibrated to deliver a maximum of 100 sccm (standard cubic centimeters per minute) N_2 (74 sccm CO_2). Flow channels 2 and 3 have controllers with a full scale range of 1000 sccm N_2 . With the calibration factors taken into account the maximum flows are 500 sccm Ethane (channel 2) and 1450 sccm Argon (channel 3). Manual valves (MV-201 & 221, etc.) are provided which allow one to bypass the mass flow controllers and use a needle-valve / rotameter set (MV-211, -212, -213) if desired. The needle valve must be closed during normal operation using the mass flow controllers.

The mass flow valves are controlled by a Dynamass Flow Control System (Vacuum General, Inc. model DM-2401). This unit is outfitted with four flow-control channels (two model FM-8 two-channel modules) and could be upgraded to eight flow channels if desired. Refer Figure5.32 for a diagram of this system. Currently HAWGS has only three of the four channels instrumented. The FM-8 receives a flow measurement from its associated flow controller, adjusts it by the calibration factor for the gas being used, and displays the result on the front panel. If the measured flow differs from the desired flow as

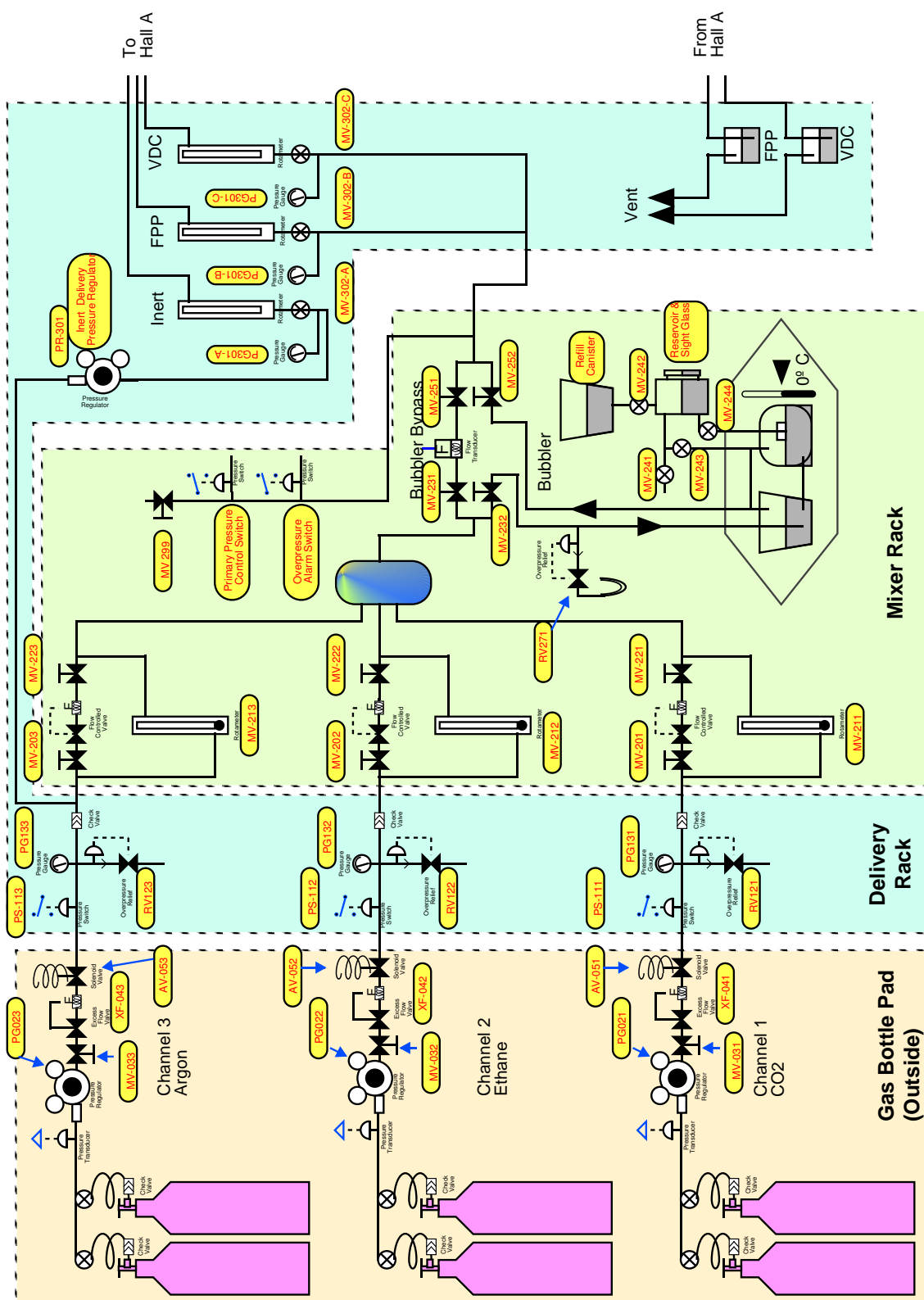


Figure 5.31: Shed Schematic Diagram

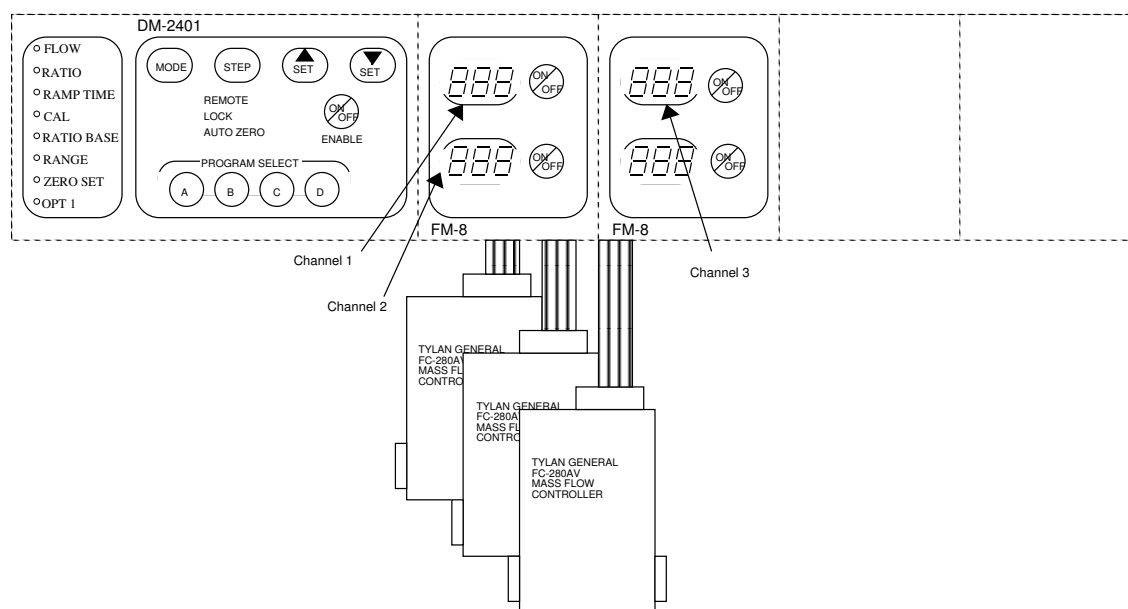


Figure 5.32: Block Diagram of Mass Flow Control System.

set in the FM-8 by an operator, a correction signal is sent to adjust the valve in the flow controller. The DM-2401/FM-8 system allows the user to define up to four mixture/flow settings. Refer to the Dynamass System manual and to section 3.3.3 *Setting a Flow Rate* for more detail on operating the flow controllers.

The measured flows of the three component gasses are combined in a small blending tank in the back of the mixing station. The resulting mixture is delivered to the alcohol bubbler through a line which is teed to an overpressure relief valve (RV-271) set for 25 psig. This prevents overpressuring of the blending tank, the bubbler, or the delivery lines.

Alcohol Bubbler

Because the interesting alcohols for use in wire chambers have a feeble vapor pressure at room temperature, it is not convenient to purchase bottled gas with alcohol already added. A practical means of adding alcohol vapor to a gas is to pass the gas through a reservoir of the liquid alcohol which is maintained at a specified temperature. At a given temperature, the vapor pressure of the alcohol may be known, and this vapor pressure represents directly the partial pressure of the vapor in the gas mixture. The vapor pressures of organic compounds may be calculated from information in the CRC Handbook of Chemistry and Physics, where it has been parameterized as

$$\text{Log}_{10}P = (-0.2185A/K) + B \quad (5.1)$$

where P is the pressure in Torr, K is the temperature in Kelvin, and A and B are parameters provided in the Handbook for a number of compounds. For isopropanol

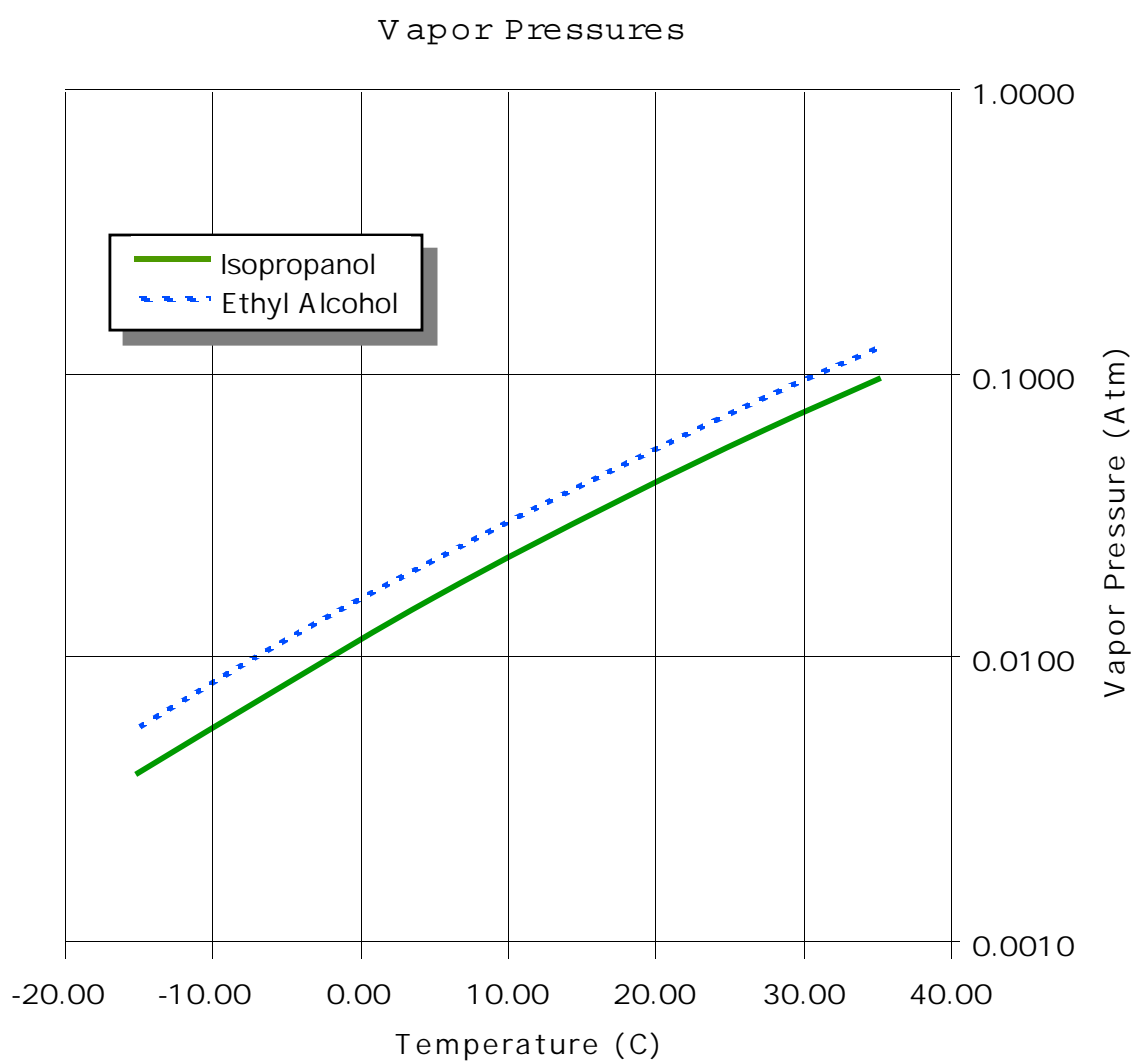


Figure 5.33: Vapor Pressures of Isopropyl and Ethyl Alcohols calculated using the CRC Handbook parameterization.

within the temperature range -26.1°C to $+232.0^{\circ}\text{C}$, the parameters given are $A=10063.5$ and $B=8.996156$. For Ethyl Alcohol the parameters are $A=9673.9$, $B=8.827392$.

At 0°C , for example, this formula gives the vapor pressure of isopropanol as 0.0115 Atm. (1 Atm. 760 Torr). If the gauge pressure of the bubbler gas + vapor is 1 atmosphere (2 Atm absolute pressure), as intended for Hall A, then the fraction of alcohol vapor, by partial pressure, is about 0.57%. Figure 5.33 shows the vapor pressures of these alcohols as a function of temperature.

Note that the bubbler temperature defines the vapor pressure and thus the dew point for the vapor in the gas. If the gas comes in contact with any surface which is colder than the dew point (the temperature of the bubbler) the alcohol vapor will condense on that surface. This is why it is important that all components of the gas system be maintained at a temperature above that of the alcohol bubbler. Because gas in the Hall A chambers is at about 1 atmosphere absolute pressure while that in the bubbler is at twice this pressure, the dew point for the gas in the chambers is lower than the bubbler temperature. The bubbler system consists of a refrigerator, a bubbler tank, a cold reservoir, a warm reservoir, and a fill tank. A float valve automatically maintains the liquid levels in the bubbler tank and the cold reservoir. Alcohol enters the bubbler tank only from the cold reservoir so that its temperature has already been established. The warm reservoir, sitting above the refrigerator, is equipped with a sight glass and serves as the main on-line alcohol storage vessel. When the level of liquid in this tank becomes low it must be manually refilled from commercially supplied bottles using the fill tank. The refrigerator used to maintain the alcohol bubbler temperature has been modified specifically to make it safe for containing flammable gasses and liquids.

Filling the alcohol reservoir is not trivial. Please refer to and carefully follow the procedure detailed in section 3.3.2 *Adding Alcohol*.

Delivery Pressure Control

Gas will be metered to each detector element through a needle valve. To achieve a constant flow through a needle valve a constant differential pressure must be maintained across it, so it is necessary to provide a fairly constant supply pressure out of the mixing station. This comes only at a price, as the mass flow controllers deliver a fixed *flow rate* regardless of pressure (within practical limits). If the detectors in Hall-A consume less gas than the mixer supplies, the pressure in the supply lines will increase. Similarly, if less gas is mixed than is consumed the pressure will decrease. To provide a usefully constant pressure of about 15 psig in the supply line, a pair of pressure switches has been installed in the mixing station outlet. The first of these, the **Primary Pressure Control Switch**, is set to open at 16 psig and close again at 14 psig or below. When the pressure is low this switch is closed and the Flow Control System is commanded to use the flow rates set into its PROGRAM C ("high flow"). When the **Primary Pressure Control Switch** opens, PROGRAM-D ("zero flow") is selected. By setting PROGRAM-C to provide just a little more gas than required by the detectors, the supply pressure can be maintained at between 14 and 16 psig. with a cycle time of several minutes. This pressure variation

will result in a flow rate variation of no more than about 15%, which should be of no consequence for the detectors.

A second pressure switch, the **Overpressure Alarm Switch**, is calibrated to open at 18 psig and re-close at 14 psig or below. If the delivery line pressure manages to exceed the 18 psig threshold it indicates a system failure of some sort and the gas interlock system is tripped by this switch. Manual operator intervention is then required to re-establish gas flow.

Pressure control of the inert gas supply, used to purge the detectors, is provided by a conventional single-stage regulator (PR-301) mounted inside the delivery rack. This regulator receives 45 psig inert gas (the same gas delivered to mixer flow channel 3) and provides 15 psig gas to the INERT supply line to Hall-A.

5.8.3 Gas Delivery into Hall A

Between the gas shed and the two Hall-A shield houses are several gas line runs of about 700 feet in length. These are shown schematically in Figure 5.34. Three gasses (inert, VDC, and FPP) are supplied to the Hadron Arm through 1/2-inch OD polyethylene tubing. Two similar tubes are teed into these near the beamline entrance to Hall-A and they supply VDC and inert gas to the Electron Arm shield house. The pressures in all of these lines is nominally 15 psig.

Distribution in the Shield Houses

Inside each shield house there is a gas distribution panel which controls the gas flows to the individual wire chambers in that detector stack. Figure 5.34 shows a diagram of the shield house gas systems.

Each gas supply is first filtered and fed to a visual pressure gauge (PG-401-A/B and PG-501-A/B/C) so that the supply pressure can be locally verified. Inert gas (for purging detectors) and operating gas (either VDC or FPP gas) is manifolded to a series of three-way valves one for each detector flow circuit. These valves are labeled MV-411, -412 in the Electron Arm, and MV-511 MV-516 in the Hadron Arm.

The three-way valve associated with each detector may be used to select either operating or purge gas independently of the other detectors. The selected gas is supplied to the inlet of a needle-valve / rotameter combination (labels MV-42x and MV-52x) which is to be used to set and observe the gas flow to each detector. The rotameters are sized for reasonably accurate metering of 5 slph Argon-Ethane and purging at about ten times this rate. (Note that the gas mixer will supply a total of only 60 slph Argon-Ethane, limited by the capacity of the Ethane mass flow controller).

On its way from the rotameter to the detector the gas passes by an overpressure relief bubbler which is basically a manometer filled with mineral oil. The overpressure bubblers are set to release at a pressure greater than about 30 mm of water (~ 33 mm mineral oil). This pressure is sufficient to allow purging at the desired rate. Gas returning from the detector passes through an electronic mass flow meter and through a low pressure

oil bubbler. This bubbler prevents backstreaming of waste gas into the detectors. The flow meter reading is indicated locally on a LCD display and is available as an analog signal for connection to the slow controls computer. Note that these digital flowmeters are factory- calibrated for Nitrogen. To correct the readings for Argon multiply by 1.45; for Ethane multiply by 0.5; for CO₂ multiply by 0.74.

Waste Gas Collection and Venting

Gas coming from the chamber exhaust bubblers is collected in a manifold and routed back to the gas shed through a large (1-inch OD) polyethylene tube. There are separate manifolds and exhaust lines for the VDC and FPP systems. Back-pressure in the exhaust manifolds is monitored by PHOTOHELIC(*R*) pressure switches. If more than about 1-inch H₂O backpressure develops in an exhaust manifold the gas supply interlock system is tripped, turning off the gas supply at the solenoid valves outside the gas shed. The purpose of this particular interlock is to protect the detector windows from overpressure.

5.8.4 Authorized Personnel

The following personnel are responsible for problems concerning the gas system:

Howard Fenker -x7431

Jack Segal -x7242

5.8.5 Safety and Device Protection

There are a number of monitor points which provide signals to the gas interlock panel and which can cause the supply of gas to be interrupted. The primary purpose of this system is to facilitate the safe handling of a flammable gas. A secondary but equally important function is protection of the detector hardware. Finally, this system serves to help insure the integrity of the data collected by Hall A experiments by alerting the experimenters on shift if a condition arises which might affect the detector gas quality. The conditions monitored are 1) flammable gas leak detection, 2) low main supply pressure, 3) high delivery pressure, 4) high exhaust line pressure, 5) forced airflow in gas shed, 6) over-temperature in gas shed or a shield house, and 7) house fire alarm. The "Kill Gas" buttons in the counting room and in the gas shed also feed into this interlock system.

When a fault condition occurs, power to the solenoid valves controlling gas flow into the gas shed is turned off, closing the valves. An audible alarm sounds in both the gas shed and the counting room, and one or more red lights on the interlock panels in both locations indicate the specific fault detected. The audible alarm may be silenced by pressing the "Alarm Override" button. Note that this does not restore gas flow or clear a fault.

After the fault is cleared it is necessary to activate the "Low Pressure Override" circuit by pressing the corresponding button on the interlock panel in the gas shed. This

Figure 5.34: Gas Distribution inside Hall-A.

circuit temporarily disables the "Low Pressure" fault circuit, allowing the solenoid valves to open up and restore gas pressure to the inlet pressure switches. When pressure is restored this circuit automatically resets itself.

Note that the **Excess Flow Valves** will almost always trip immediately after the solenoid valves are re-opened. This is because of the sudden high flow rate which occurs when the pressure in the gas line downstream of a solenoid valve is low and the solenoid valve is opened with full inlet pressure. To reset the **Excess Flow Valves** refer to the section *Resetting a closed Excess Flow Valve*.

5.8.6 System Operation

Pre-Startup Checklist

Before initial use with a flammable gas or after a significant down-time the following checks should be made to insure the safety and integrity of the HAWGS:

1. Leak-Check the entire gas system using a safe gas such as Argon or Nitrogen.
2. Calibrate over-pressure relief valves: RV121, 122, 123 should release at 55-65 psig, RV271 must release at 20-25 psig).
3. Check calibration of Excess-Flow valves (should close at 4-5 slpm).
4. Check proper operation of each interlock circuit and that interlock system shuts off gas supply.
5. Measure the detectors leak rates and verify that each is below 7 slph (or current administrative limit - note that current physical limit is 500 sccm Ethane and 1450 sccm Argon based on flow controller full scales for N₂ and correction factors for Ethane and Argon).
6. Verify that flammable gas leak sensors are appropriately calibrated.

Startup Procedure

1. Close gas shed outlet valves MV-302-A, -B, -C to isolate the mixing/delivery system from the spectrometer detectors.
2. Activate the "Kill Gas" crash button. Interlock panel should alarm. Silence the alarm by pressing "Alarm Silence". Reset the Crash Button by pulling outward. If any fault conditions (red LED) other than "Low Pressure" and "Main Relay" are indicated, clear them by correcting the indicated fault.
3. Check alcohol supply and Bubbler temperature. Fill and/or adjust as necessary (see *Adding Alcohol*) .

4. Check that adequate supply bottles of appropriate gasses are attached to the high pressure supply manifolds and valve **one** bottle ON for each manifold.
5. Verify that all used main pressure regulators (outside) are set for 45-50 psig.
6. Select "Manual / Expert" pressure control using toggle switch on panel in rear of mixing station, behind flow controller. **Note that while in "Expert" mode there is no automatic delivery pressure control!** Overpressure is prevented only by the overpressure shutoff switch and the alcohol reservoir relief valve.
7. Verify that the Dynamass Flow Control System DM-2401 is in "Non-VG" mode by
 - Press PROGRAM SELECT pushbutton A.
 - Put the DM-2401 in NO-MODE mode (if it is not already) by pressing the MODE pushbutton until all LEDs in the column of LEDs on the left of the unit are off.
 - Simultaneously press and release PROGRAM SELECT buttons A and C.
 - Press the MODE pushbutton until the OPT 1 LED is lighted. Verify that the display for channel 4 reads all zeros.
 - Return the DM-2401 to NO-MODE.
8. Set Dynamass Flow-Control System to Program "D: Zero Flow". Put the DM-2401 in "FLOW-MODE" and verify that all flow settings are at zero.
9. With the DM-2401 in "FLOW-MODE", set up flow program "C" to provide the desired mixture at about 10% higher total flow than the detectors are expected to consume.
10. Return the DM-2401 to "NO-MODE".
11. Select "Auto" pressure control using toggle switch on panel in rear of mixing station, behind flow controller.
12. Actuate the Low Pressure Override on interlock panel. "Main Relay" light should become green.
13. Set Excess-Flow Valves and Manual valves at regulators to full OPEN, wait about ten (10) seconds for supply lines to come up to pressure, then set all three Excess Flow Valves to AUTO SHUTOFF. - "Low-Pressure" interlock circuit should go to green during this step³.
14. Verify proper operation of flow/mix control system and outlet pressure regulation by observing flow rates on the mixer control and outlet pressure at the supply rack (pressure gauges 301B, -301C). If the alcohol bubbler loop is valved on it may take several minutes for its volume to fill with gas and come up to pressure. Be

patient. When the pressure indicated on gauges PG301-B/C reaches about 15 psig the DM2401 system should cycle to flow program D. To bleed down the outlet pressure in order to cause the pressure loop to cycle, you may crack valve MV-299 (located in the rear of the mixer rack). When the pressure drops back to about 13 psig the control system should switch back to program C. Re-close valve MV-299 when tests are complete.

15. Check/Adjust the Purge gas pressure regulator (PR 301) to insure that the delivery pressure of the inert gas (taken from gas supply 3 - nominally Argon) is about 15 psig as registered on pressure gauge PG-301A.
16. Slowly open gas shed outlet valves MV-302-A, -B, -C to bring up the pressure in the supply lines to the spectrometers. After pressure has equalized open these three valves fully. Note that one or more **Excess Flow Valves** will trip (close) if the **total** gas flow through the three rotameters associated with these valves exceeds (roughly) 150 units (full scale on **one** rotameter).
17. At each of the Hadron and Electron shield house gas distribution racks, verify the presence of supply pressures (gauges PG401A,B and PG501A,B,C) and set gas selection valves and needle valves to desired gasses and flow rates for each chamber.

Normal Operation

Changing gas bottles

Warning: High pressure gas bottles contain significant stored energy and are potentially hazardous. Handling of gas bottles should be done only by qualified, trained personnel.

For smoothest operation, used gas bottles should be replaced before their internal pressure drops below the desired regulator output pressure.

The sequence of steps for replacing an empty gas bottle is as follows:

1. Make sure that the backup bottle is full, then open its bottle valve and its manifold valve. The in-line check-valves will prevent back-filling of the empty bottle. As a precaution, set the corresponding **Excess Flow Valve** to **OPEN/RESET**, wait ten seconds, then set the **Excess Flow Valve** back to **AUTO**.
2. Close both the bottle and manifold valves for the empty bottle.
3. Disconnect the empty bottle from the high-pressure flex-line, replace the bottles cap, and move the empty bottle to the EMPTIES storage rack. Note that ethane bottle fittings, type CGA-350, have left-handed threads.
4. Place a full bottle of gas in the on-line rack, remove the bottle cap, and connect the bottle to the flex-line.
5. Open the new bottles valve, check for leaks at the bottle fitting, then re-close the bottle valve.

Adding Alcohol

Warning: Never open gas flow into the alcohol bubbler without an outlet valve being open.

As long as the level in the **RESERVOIR** is such that some alcohol is visible in the sight glass the bubbler will be maintained at its normal fill. An effort should be made to prevent the **RESERVOIR** level from getting too low.

1. To fill the **RESERVOIR** close valves MV-243 and MV-244 to isolate the **RESERVOIR** from the pressure equalization line.
2. Open valve MV-241 to vent the **RESERVOIR**.
3. Remove the cover of the **REFILL CANISTER** and fill the canister with alcohol. Put the cover back on but do not seal it (if you seal the cover at this point the flow of alcohol out of the **REFILL CANISTER** will be impeded).
4. Open valve MV-242 to let the alcohol into the **RESERVOIR**. The liquid level can be monitored in the sight glass on the side of the **RESERVOIR**. Fill until the liquid level is near the top of the sight glass then close MV-242. **Do not overfill** (to or above the top of the sight glass).
5. Close valve MV-241, then open valves MV-243 and MV-244.
6. Seal the cover on the **REFILL CANISTER** to prevent contamination.

Setting a Flow Rate

The flow of each individual gas component, and therefore the final gas mixture, is controlled by the **Dynamass DM-2401 System**, the **FM-8 Flow/Ratio Modules**, and the **Tylan General FC-280 Mass Flow Controllers**. The **DM-2401** accepts and stores programs for the set of **FM-8's**. Each **FM-8** controls one or two **Mass Flow Controllers**.

To set or alter a flow rate:

1. Prevent the mixed-gas outlet pressure from exceeding its 18 psig interlock trip level by either a) closing valves MV-201,2,3, or b) insuring that the detectors are consuming a sufficient quantity of gas to prevent this overpressure from occurring during the time it takes you to perform steps 3-11, below.
2. Set the Auto/Expert pressure control switch (rear of mixer rack) to **EXPERT**.
3. Verify that the **DM-2401** is in the **NO-MODE** mode, indicated by none of the LEDs in the column on the extreme left of the unit being illuminated. If necessary, press the **MODE** pushbutton until this condition is achieved.
4. Press program select button **C** and verify that the corresponding LED illuminates.

5. At the DM-2401 Keyboard module, press the MODE switch until the FLOW LED illuminates. The window value for channel 1 will begin to flash.
6. Select the channel you wish to alter by pressing the STEP button until the window value of the desired channel is flashing.
7. Press the UP or DOWN SET buttons to alter the value as desired. Legal flow values are 0.0-100.0 sccm for channel 1, 0-1000 sccm for channels 2 and 3.
8. If the Red ON LED for the desired channel (immediately to the right of the value window) is not lit, press the ON/OFF button for that channel to illuminate this LED.
9. Repeat steps 6-8 as necessary to program all desired gas flows.
10. Return the DM-2401 to NO-MODE as in step 3.
11. Return the Auto/Expert pressure control switch (rear of mixer rack) to AUTO.
12. Re-Open valves MV201, 202, 203, if closed in step 1.
13. Observe system flow and pressure control and verify that it is correct.

5.8.7 Troubleshooting : Things to Check

Each of the following monitor points must report a nominal condition to the gas interlock panel in order for the logic to be "made up" and for gas flow to be enabled:

Label	Meaning	Likely Remedy	Sensor
Low Pressure Note: <i>This channel will always indicate a fault after some other problem has caused the solenoid valves to close.</i>	The secondary pressure of one or more of the mixer inlet gas supplies has dropped below the 45 psi threshold.	<ul style="list-style-type: none"> • Check for a closed "Excess Flow" Valve, Remedy the cause, and reset the valve • Replace empty supply bottle. 	3 pressure switches located on the "Delivery Rack"
Gas Shed Airflow	Gas Shed Exhaust Fan (ceiling of "Isobutane Room") has failed.	Restore forced ventilation.	Vane Switch mounted just inside exhaust fan
Overtemp Gas Shed	Temperature in Gas Shed Too High ($\sim 110^{\circ}\text{F}$).	<ul style="list-style-type: none"> • Take action to protect equipment. • Reduce temperature. 	Klixon mounted in rack
Over-Pressure FPP Over-Pressure VDC Electron Over-Pressure VDC Hadron	VDC/FPP Exhaust manifold pressure at Hadron Or Electron Shield House Gas Rack	<ul style="list-style-type: none"> • Eliminate exhaust line blockage • Allow Hall-A atmospheric pressure to stabilize 	PHOTOHELIC ^(R) gauges on gas panels in shield houses
Gas Leak	Flammable gas detection system has sensed a leak	<ul style="list-style-type: none"> • Localize leak by referring to readings on GasMaster-4 system in Counting House • Fix Leak 	GASMASTER HydroCarbon Detector heads in Gas Shed and each Shield House.
Overtemp Electron	Temperature in Electron Shield House Too High ($\sim 110^{\circ}\text{F}$).	<ul style="list-style-type: none"> • Take action to protect equipment. • Reduce temperature 	Klixon mounted in gas rack in Electron Shield House
Overtemp Hadron	Temperature in Hadron Shield House Too High ($\sim 110^{\circ}\text{F}$).	<ul style="list-style-type: none"> • Take action to protect equipment. • Reduce temperature. 	Klixon mounted in gas rack in Hadron Shield House
Post-Bubbler Supply Overpressure	Gas pressure out of mixer/bubbler rack is >18 psi.	<ul style="list-style-type: none"> • Reset Dynamass Controller • If needed, vent excess pressure using MV-299 	Pressure switch in rear of Mixing Station (mixer/bubbler rack)

Resetting a closed Excess Flow Valve

Each Excess Flow Valve automatically closes if the flow rate through it exceeds about 4 slpm at 45 psig. The exact flow threshold varies somewhat depending upon the delivery pressure.

These valves must be manually reset after they trip. This is done by rotating the red handle 90° CW (to OPEN/RESET) and then 90° CCW (back to AUTO SHUTOFF.). It will be necessary to keep the valve in the OPEN/RESET position for about 10 seconds until nominal pressure builds up downstream. The excess flow valves must be returned to the AUTO SHUTOFF setting to insure system safety.

Restoring flow after a "Low Supply Pressure" shutdown

If the gas pressure in any enabled supply line to the mixer rack drops below about 40-45 psig, the interlock will sound an alarm and close all of the solenoid valves. This prevents the system from delivering a bad mixture to the detectors. After restoring the gas supply, for example, after replacing an empty gas cylinder, perform the following steps to restart the flow of gas.

1. Verify that no faults other than "Low Pressure" and "Main Relay" are indicated on the gas interlock panel.
2. Insure that all high-pressure manifolds are pressurized and that the secondary pressures indicated by the gauges above the bottles are at about 40-45 psig (normally these should not need adjustment).
3. Press the Low Pressure Override button on the interlock panel in the gas shed.
4. Reset all Excess Flow Valves by turning their handles to OPEN/RESET, waiting for about ten seconds, then returning their handles to AUTO SHUTOFF.
5. Verify that all faults are now cleared on the gas interlock panel.

Restarting flow after a power failure.

Normally the gas control system is protected from power outages by an uninterruptable power supply (UPS). If the system is nevertheless disturbed by a loss of power then perform the steps outlined in section 3.2, Startup Procedure.

5.8.8 Maintenance

Periodic Inspections

Anytime work is done on any part of the gas system, or there is an occurrence that could possibly have damaged the gas system, the system should be carefully inspected and checked for leaks.

The flammable gas detector heads and control system should be tested periodically for proper operation, in accordance with the manufacturer's recommendations and the TJNAF fire safety program.

Each sensor feeding the Gas Interlock Panel should be exercised at least annually for proper operation. The interlock system itself should be tested at the same time to insure that it interrupts the supply of gas when it is tripped.

The high-pressure manifold and bottle connections should be regularly checked for leaks and damage. In particular, the CO₂ system (CGA-320) uses plastic seals at the bottle connection which must be replaced periodically.

Flowmeter Calibration The Tylan General mass flow controllers (mass flow valves) require periodic cleaning and calibration (section 5.7, Tylan General Mass Flow Controller Instruction Manual). The first step in this process is to check the operation of the instruments and perform further work as necessary. This procedure should be planned and carried out whenever 1) there appears to be a problem with the operation of a flow controller, or 2) there is a lengthy break in the Hall-A program that would allow the gas system to be taken off-line for several weeks. If absolutely necessary the needle-valve/rotameter combinations plumbed in parallel with the mass flow controllers could be used to allow interim operation of the gas system while one or more flow controllers is removed for maintenance.

Chapter 6

Slow Controls

6.0.1 Hall A Slow Controls ¹ ²

6.0.2 Introduction

The Hall A base equipment for experiments consists of two general purpose, similar, superconducting spectrometers and their associated detector packages as well as several specific function systems (i.e. cryogenic targets, ^3He target, beam current monitors, ARC energy measurement system, e-p energy measurement systems and so on). Each of these major systems is, typically, composed of several sub-system levels which need to be interlocked for protection of human life and/or equipment, monitored for operational status and commanded to perform various operations so that the system as a whole is able to perform the desired measurement or function. Most of these sub-systems have an infrastructure role; they are essential for the correct operation of the major system of which they are part but, in themselves, are irrelevant for the experimental physics data being acquired. An example could be the cryogenics of one of the spectrometer magnets; proper cryogenics filling of the magnets is absolutely essential for the magnets to operate but, for a given experiment, the relevant quantities are the spectrometer momentum and optics produced by the various active magnets and not the cryogenics levels of each magnet. The task of monitoring and commanding the infrastructure of the various Hall A systems falls on a distributed computer system loosely referred to as “slow controls” or “Hall A Controls (HAC)”.

6.0.3 Hall A Controls Overview

The Hall A distributed control system is based on the Experimental Physics and Industrial Control System (EPICS) [19]³ architecture. The basic components of the system are:

¹ *CVS revision* Id: HacOps.tex,v 1.4 2003/06/06 17:19:22 gen Exp

² Authors: J.Gomez <mailto:gomez@jlab.org>

³ <http://www.aps.anl.gov/asd/controls/epics/EpicsDocumentation/WWPages/EpicsDoc.html>

- Operator Interfaces (OPI). These are UNIX based workstations able to run various EPICS tools like the Motif-based Display Editor/Manager (MEDM) used by the operators for display and command of the various systems.
- Input Output Controllers (IOC). These are VME based crates containing a single board computer with the real-time operating system VxWorks and various I/O modules as well as interfaces to other I/O busses like serial or GPIB.
- Boot Servers. These are UNIX based workstations from which the IOCs load the various software components they need to perform their functions (i.e. operating system, database of signals to be monitored/commanded, controls algorithms and so on).
- Local Area Network (LAN). This is the communication path joining the IOCs, OPIs and the Boot Servers.

Signal monitoring and command is performed by the IOCs. At the heart of an IOC is a memory resident database describing each of the signals to be monitored and controlled by the IOC. Each database entry (record) corresponds to a signal. When a given record executes, it accesses the appropriate I/O module to retrieve/update the signal value. The origin of this record execution request can be local to the IOC (i.e. another database record) or remote (i.e. operator intervention through an OPI or a record located in another IOC). In all cases, access to the record is by name and not by IOC location. The general EPICS mechanism to access a record consists of broadcasting the record name in the network. Upon receiving the broadcast, every IOC in that network searches its database to determine if it contains the record name being sought. The IOC holding the requested record responds to the query establishing a connection with the querying process.

The interface provided by the IOCs to access their record database is geared towards efficiency and not human friendliness. Two reasons dictate this choice: minimization of CPU overhead due to interface management and the fact that the system is distributed. Operator access to the record database of a given IOC is through a Graphical User interface (GUI) process executing in a UNIX based computer. The standard distribution of EPICS comes with a Motif based implementation of such GUI, the so-called MEDM. It is possible to also implement a GUI to the IOCs using the Tool Command Language (TCL) with X11 extensions (TK) (i.e. TCL/TK). Such implementation is used, for example, by the Hall A cryotarget system. There can be many instances of these GUIs executing in the same computer as well as in several different computers (i.e. the GUI processes are also distributed). Each of these GUI processes can access multiple IOCs simultaneously and within each IOC, all or a subset of the database records. The computers where these GUIs execute are referred to as the OPI.

Figure 6.1 shows a schematic view of the present Hall A controls layout. Exchange of signals between Hall A and other JLab control systems takes place through the main Jefferson Lab network (JLab LAN). Presently, the system is in a state of flux as management of various portions of the Hall A controls system is being transferred to the

Accelerator Division Controls Group (ADCG). This might entail future changes in the organization of the Hall A control system like boot servers and IOC task re-arrangement. A brief description of the present state of the system follows.

There are three IOCs in Hall A which at the present time are directly managed by the ADCG. These IOCs are iocse10, iochla and iochla2. They are located in the row of racks next to the beam line. Iocse10 performs the readout of the Beam Position Monitors (BPMs) located in Hall A (i.e. those located at Compton region and before the target). Iochla handles Hall A beam line tasks like Fast Shut Down (FSD) logic, Møller target motion, Beam Loss monitors and ionization chambers. Hall A cryogenics distribution and magnet filling/level are controlled by iochla2 through a GPIB based network of CAMAC crates. This IOC also monitors all spectrometer magnet temperatures during a magnet cooldown. The iochla2 signals are available in the Hall A controls network through a dedicated IOC (hallasc9) located in the electronics room (middle room) of the Hall A Counting House. Only Accelerator Operations personnel are allowed to reboot and/or perform any hardware/software changes in iocse10, iochla and iochla2 and the associated equipment that they control. If necessary, hallasc9 can be rebooted by pressing the “RESET” push button located in the IOC front panel. Such operation does not have any effect on the Hall A cryogenics distribution itself (hallasc9 does not control any hardware, it is simply a signal repeater). If a magnet cryogenics problem develops in Hall A, the Hall A on-call technical staff should be notified.

The controls layout of each High Resolution Spectrometer (HRS) is similar; each consists of three IOCs which monitor and control the detector package infrastructure, general spectrometer functions and, spectrometer motion. In the case of the hadron HRS, these IOCs are hallasc4, hallasc16 and hallasc7. Hallasc4 and hallasc16 are located inside the detector hut. Hallasc4 is in the second floor of the detector electronics racks while hallasc16 is located under the Box Beam supporting the detectors and detector electronics. Access to hallasc16 is through a “manhole” located at the back of the detector hut. The IOC in charge of the hadron HRS motion is located right at the back of the dipole (power supplies level). In the case of the electron HRS, the IOCs are hallasc11, hallasc14 and hallasc18 respectively. Their location is similar to their hadron spectrometer counterparts.

The tasks assigned to IOCs hallasc7 and hallasc18 are well defined and unique: spectrometer motion. Hallasc4 monitors/controls the Vertical Drift Chambers (VDCs) High Voltages (HV), discriminator threshold levels and the low voltage power supplies for the discriminator cards as well as the Focal Plane Polarimeter (FPP) tracking chamber’s HVs, discriminator levels and low voltage power supplies. Hallasc4 also controls the operation of the FPP carbon doors as well as monitoring the gas flow to the FPP tracking chambers and VDCs. In the case of the electron HRS, the corresponding IOC (hallasc11) monitors/controls similar quantities for the VDCs only (there is no FPP system). The general spectrometer infrastructure IOCs (hallasc14 and hallasc16) monitor/control magnets power supplies, field probes, hardware interlock systems and power leads cryogenic cooling, collimator motion, magnet/spectrometer vacuum and spectrometer horizontal/vertical angles. If a problem arises, all these IOCs can be hardware reset

from the Hall A Counting House through the green buttons panel located in the middle room.

There is an extra IOC, hallasc22, located on the second floor of the electron HRS detector electronics racks (inside the detector hut). This IOC monitors and controls, through a private network, various high voltage power supplies. Two of these supplies are located in the electron HRS detector hut, one in the hadron HRS detector hut and one along the beam line. These power supplies are used by various systems like the spectrometer scintillator planes (trigger), gas Cerenkov and Aerogel counters, electron HRS calorimeter, FPP, hadron HRS calorimeter (when installed) and various beam line systems like the ARC energy measurement system.

The beam line IOC hallasc12 is reserved, at this time, for Hall A application testing and development. There are other specific purpose IOCs located in the group of electronics racks next to the beam line. The reader is referred to the specific description of those systems and related instructions elsewhere in this OPS manual.

There are several Hall A controls related IOCs and computer systems outside the hall. Some of them are specific purpose systems described elsewhere in this manual like the 9th magnet Bdl IOC and associated ARC workstation located inside the 9th magnet shed, and they are described elsewhere in this manual. The others are briefly described below.

Hallasc17 is located in the gas shed. It monitors the supply of gas used by the tracking chambers (i.e. VDCs and FPP chambers). If necessary, hallasc17 can be rebooted by pressing the “RESET” push button located in the IOC front panel. Hallasc5 is located in the electronics room of the Hall A Counting House (middle room) in the same VME crate than hallasc9. Hallasc5 monitors signals associated with Hall A beam current. It can be reset by pressing the “RESET” push button located in the IOC front panel. The remaining computers and X-terminals associated with the Hall A controls are used as OPI and/or boot servers for the IOCs. One of the X-terminals in the counting house is dedicated to the display of accelerator MEDM screens (it is automatic, no user involvement is required).

The “hac” computer is used to gain access to the Hall A control systems. Once logged into this computer, issue the command “HAC_hp” if logging was accomplished through a Hewlett Packard computer console or “HAC_xt” if through an X-terminal. The Hall A controls main screen shown in Figure 6.2 will appear. Follow then the instructions given in the system of your interest.

6.0.4 Personnel Responsible

If a problem develops with the Hall A controls system, page J. Gomez at 849-7498.

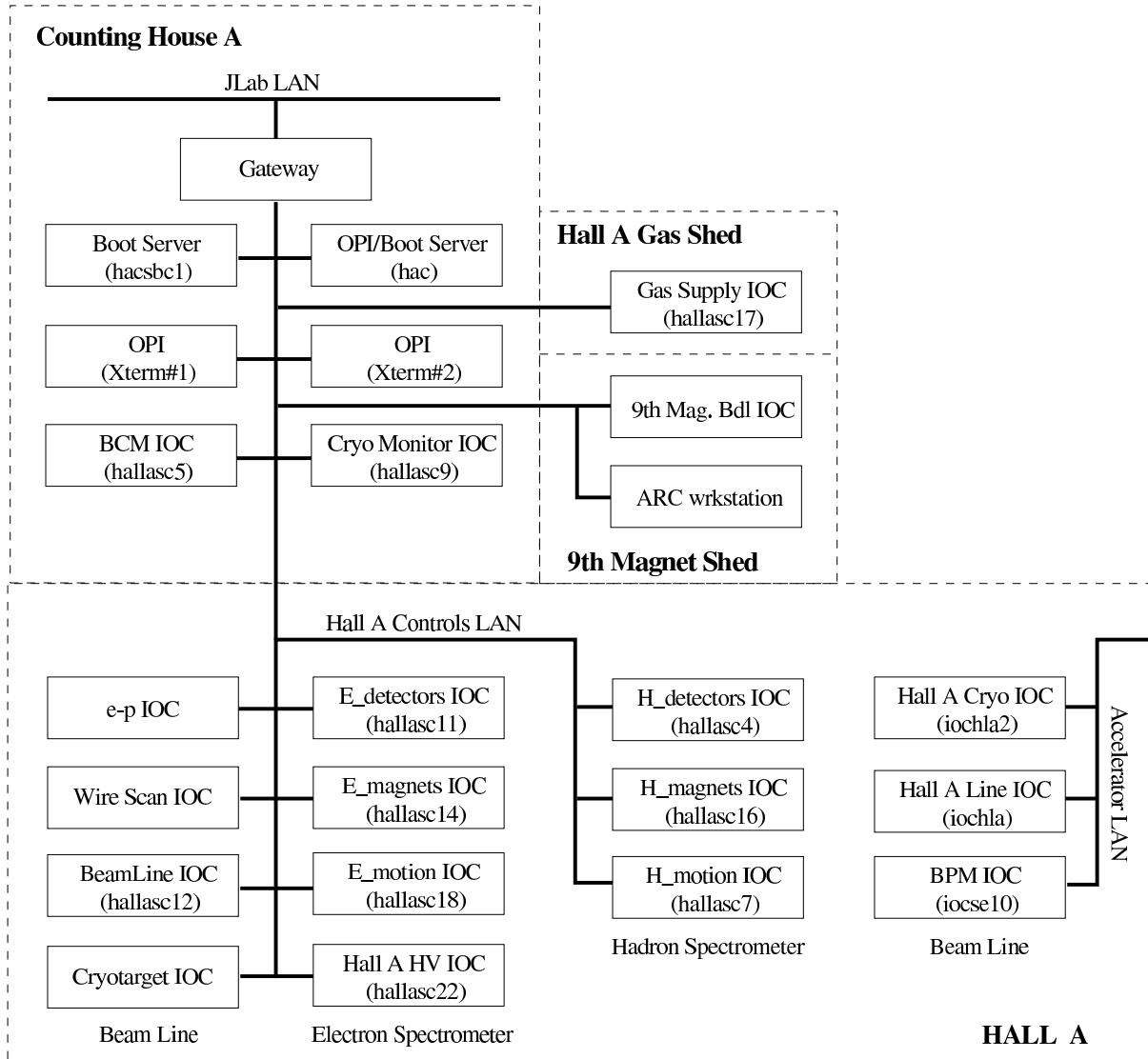


Figure 6.1: Schematic of the Hall A controls system.

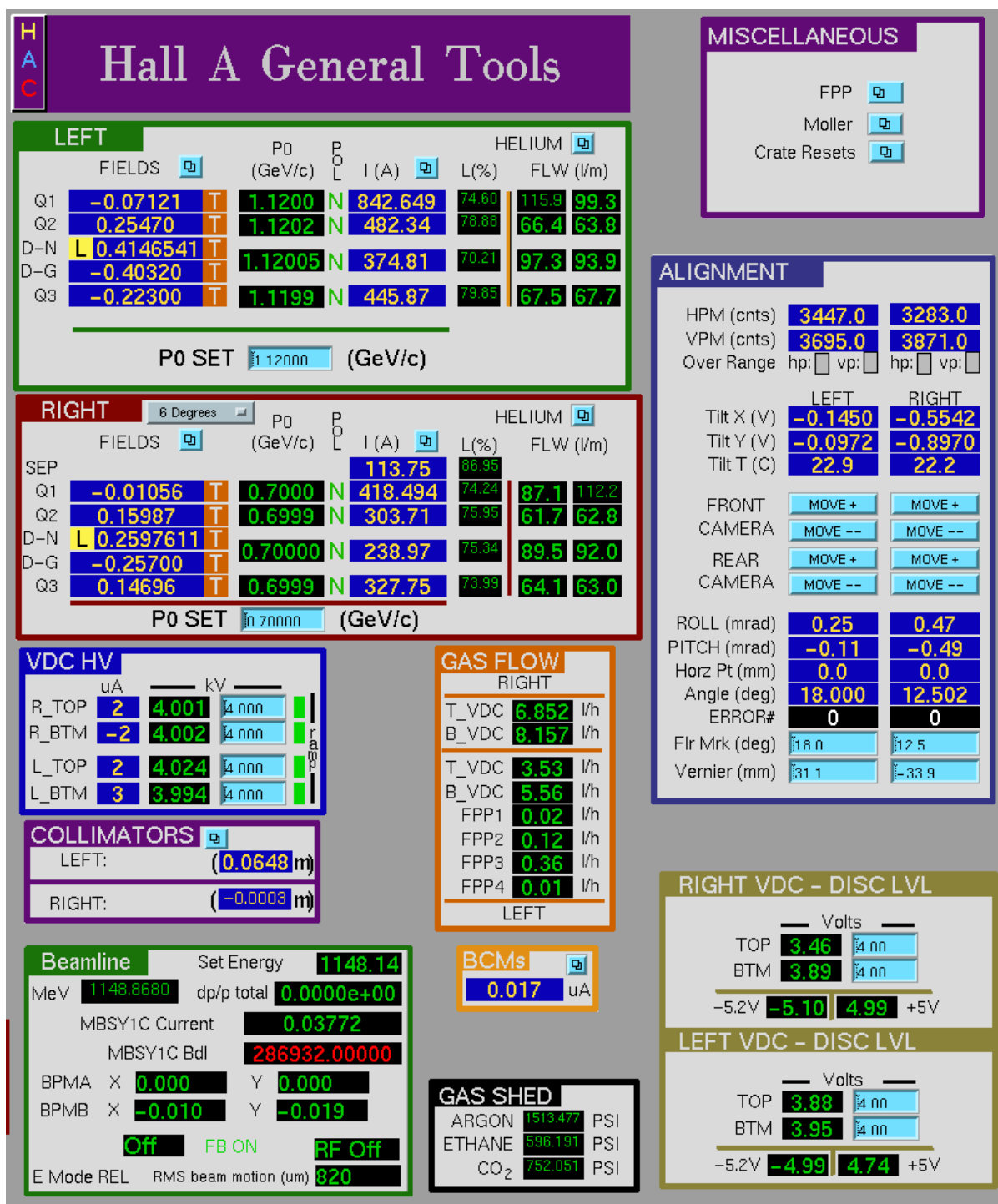


Figure 6.2: Hall A Main Control Screen.

Chapter 7

Data Acquisition and Trigger

7.1 Spectrometer Data Acquisition ^{1 2}

The Hall A data acquisition uses CODA [4] (CEBAF Online Data Acquisition), a toolkit developed at Jefferson Lab by the Data Acquisition Group. For general information about CODA, see the CODA site³. Up to date information about the Hall A DAQ is kept at ⁴.

We typically run with two fastbus crates in each spectrometer, plus VME crates for scalers. The fastbus modules are of the following types: (1) LeCroy model 1877 TDCs operating in common-stop with 0.5 nsec resolution for our drift chambers and straw chambers; (2) model 1875 TDCs operating in common-start with 0.1 nsec resolution or 0.05 nsec resolution depending on the setup, for our scintillators and trigger timing; and (3) model 1881M ADCs for analog signals from scintillators, Cerenkov, and leadglass detectors. In some run periods the beam position monitors and raster current were available in a VME system, but presently they are read out in fastbus.

The trigger supervisor is a custom-made module built by the data acquisition group. Its functions are to synchronize the readout crates, to administer the deadtime logic of the entire system, and to prescale various trigger inputs. We have two trigger supervisors, one in each spectrometer. This allows us to run the spectrometers independently if needed.

The public account “a-onl” is normally used for running DAQ and “adaq” is used for running other online software including ESPACE or the C++ analyzer. On “adaq” the directory tree of an experiment is `adaq/$EXPERIMENT` which is organized in sub-directories of various tasks, such as scaler display, ESPACE, and other online codes, all of which will be described in sections below. The trigger management software is run from the “atrig” account and is described in the Trigger chapter.

¹ *CVS revision* Id: daq.tex,v 1.4 2003/08/01 20:34:06 rom Exp

² Authors: R.Michaels <mailto:rom@jlab.org>

³ <http://coda.jlab.org/>

⁴ http://hallaweb.jlab.org/equipment/daq/daq_trig.html

7.1.1 General Computer Information

In the counting room we have various computers for DAQ, analysis, and controls. The controls subnet is the responsibility of J. Gomez and is documented in another chapter. The DAQ computer's names are denoted by `adaqXN`, where $X = s$ is SunOS and $X = l$ is for Linux PC. `adaqs1` is the Compton DAQ computer and is normally reserved by the Compton group. `adaqs2` and `s3` are for running the spectrometer DAQ or doing online analysis; we are gradually phasing out the Suns. `adaql1` and `l2` are Linux computers for running DAQ while `adaql3,4...` and higher are for analysis. The Linux PCs are administered mostly by Ole Hansen.

To reboot the Suns, login as “`adaq`” and type “`reboot`”. To reboot the Linux machines, first hit `Ctrl-Alt-F1` to switch to a text console, then hit `Ctrl-Alt-Del` to reboot. If power fails for a prolonged time, you must shutdown before the UPS fails.

7.1.2 Beginning of Experiment Checkout

This subsection describes the checkout of DAQ and trigger needed before an experiment can start.

1. First ensure that all the fastbus, VME, CAMAC, and NIM crates are powered on. They should boot up in a functional state, except for heavily loaded fastbus crates that sometimes lose their NVRAM. (If that happens, see notes in `adaq/doc/vmeram.doc`).
2. You may download a default trigger, following the directions in the trigger chapter. If the hadron momentum changes you may need to set a new delay. A trigger expert should do the start-of-experiment trigger checklist.
3. Make sure the HV is on for all detectors and that the values are normal.
4. Start the xscaler display following the instructions below and check that the rates from detectors are normal.
5. Startup runcontrol (CODA) using the directions below and start a run. With the trigger downloaded and the HV on, you are taking cosmos data, typically at a rate of 3 Hz per spectrometer. Examine the data using ESPACE or the C++ analyzer. Compare the plots and printouts to normal values.

7.1.3 Running CODA

This section describes how to run CODA for the spectrometer DAQ. There are two modes: (1) The most common is the “1-Trigger-Supervisor (1-TS)” mode which uses one trigger supervisor and is used for coincidence experiments; and (2) The “2-Trigger-Supervisor (2-TS)” mode which is used for running the two spectrometers independently.

The 1-TS mode can also handle single-arm triggers but is about 1/2 the aggregate speed of the 2-TS mode. When running the 2-TS mode, one uses the `a-onl` account on

adaql2 for one spectrometer and the adev account on adaql1 or adaqs2 for the other spectrometer. The 1-TS mode normally uses the a-onl account on adaql2 only. The information that follows refers to the a-onl account, but the other account is quite similar.

Here is how to start and stop a run. Normally, when you come on shift, runcontrol will be running. If not, see the section on “Cold Start” below. To start and stop runs, push the buttons “Start Run” and “End Run” in the runcontrol GUI. To change configurations use the “Run Type” button. If you have been running you will first have to push the “Abort” button before you can change the run type. Typically the configurations you want are the following.

TWOSPECT – For running the two spectrometers in 1-TS mode.

PEDRUN – To do a pedestal run in 1-TS mode

RIGHTHRS – For R-arm in 2-TS mode

LEFTHRS – For L-arm in 2-TS mode

PEDRUNR – To do a pulser run for R-arm in 2-TS mode

PEDRUNL – To do a pulser run for L-arm in 2-TS mode

A note about pedestal runs. They have the exclusive purpose of obtaining pedestals used for pedestal suppression. For details about what is done and hints for getting pedestals for ESPACE (which does not want the PEDRUN result), see /ped/README.

Some Frequently Asked Questions about DAQ

- *Q: Where is the data ?* Use a command “find_run 1745” to find where run 1745 has been written on disk and MSS. The data are first written to disks like /adaql2/dataN, N=1,2,3...etc. Files are automatically split, with suffixes .0,.1,.2...etc. Splitting occurs at 2 Gbytes to avoid problem of system file size limit. Files are archived automatically to tape in the MSS tape silo. Two tape copies are made. Data are purged from disk automatically. Users should *never* attempt to copy, move, or erase data.
- *Q: How to adjust prescale factors ?* Edit the file /prescale/ prescale.dat. One common problem is putting typographical errors here which then leads to no triggers getting accepted.
- *Q: What is the deadtime ?* The deadtime is displayed in the datamon window, which normally is running next to the runcontrol window, but if this window is not up, type “datamon” to bring it up. This window also shows the full-path-name of the file being written by CODA for the present run.

- *Q: Why is the deadtime so high ? (and related)* Search for answers among the following. The standard lore is that 30% deadtime is tolerable, but you should ask your analysis team to decide. Sometimes people seeing large deadtimes have forgotten to observe that the beam is in pulsed mode. Another possibility is that the workstation is overloaded. The computer used for CODA should not be used for much else. Do not attempt to read or write rapidly to the same physical disk to which CODA is writing. Sometimes it is observed that the workstation itself is very sluggish. This could be due to a foreign mounted disk having gone away, and there are other possible reasons. If a Cold Start of CODA doesn't solve the problem, you may try rebooting the workstation (see computer section). Also, if the event size changes substantially, e.g. due to VDC thresholds being turned off (a common mistake), the deadtime as a function of rate will change, especially in the regime of high rates.

Quick Resets

Problems with CODA can usually be solved with a simple reset. If not, try a Cold Start (see next section). Do not waste an hour of beam time on resets; if they fail, call an expert. The expert claims he can restart CODA 90% of the time within 10 minutes.

If a ROC (ReadOut Controller, or crate) is hung up, reboot by going the workspace "Components" and typing "reboot". If this doesn't work, try pressing the reset button which is on the "Crate Resets" section of the Hall A General Tools EPICS Gui. Telnet back into the ROC to verify its alive. Then press "Reset" in runcontrol, download and start a new run.

Cold Start of CODA

If CODA is not running, or if it gets hung up, you can do a cold start. Frequently a subset of these steps is sufficient to recover from a hangup, but it takes some experience to realize the minimum of steps that are necessary, so the simplest thing is to do them all, which takes a few minutes.

- Kill off all CODA processes on the workstation by typing "kcoda". This stops runcontrol, the event builder, and other processes, and allows for a clean start. The "kcoda" script will then tell you exactly what to do next.
- Make sure the fastbus and VME crates are running. The crates are usually known by "ROCnumber-computer-(portserver-port)" where ROCnumber is the unique number for that ROC (ReadOut Controller, or crate), computer is the internet name and the portserver-port is the portserver IP and port# where to login. An example might be ROC4-hallasfi4-(hatsv4,port3) which is ROC4, a fastbus crate with IP hallasfi4 attached to the portserver IP hatsv4 at port 3. You can check if the ROCs are up by looking on the Components work space at the telnet session (if it's not logged, try to telnet in). If the ROCs don't talk to runcontrol, you can type

“reboot” at the arrow prompt (\rightarrow). If you don’t get this arrow prompt, or if you can’t telnet in, the computer is hung up, so press the reset button in the “Crate Resets” GUI available from the EPICS screen for Hall A General Tools. After the ROC comes back (2 minutes), telnet back in to verify it’s up. On rare occasions it is necessary to power cycle the crate, which requires access.

- Start runcontrol interactively by typing “runcontrol”. Actually there may be more steps prior to starting runcontrol, depending on the experimental setup. See the printout from “kcoda” for instructions.
- In runcontrol, press the “Connect” button. After “connect” wait 10 seconds and press “Run Types”. After configure and before download, press the “Reset” button in the upper left corner. Choose the run type from the dialog box (see section on Running CODA for descriptions of run types).
- After you configure and download the Run Type, you can “Start Run” to start a new run.

Recovering from a Reboot of Workstation

If the workstation from which you are running CODA was rebooted, here is how to recover DAQ. Login as the relevant account, which is usually a-onl for 1-DAQ operation. Passwords for the online accounts should be available on a paper on the wall in the counting room, or ask the run coordinator. In the workspace for “Components” telnet into all the ROCs. If the x-terms windows are not available, type “setupxterms”. Start emacs for the prescale factors: “emacs /prescale/prescale.dat”. Make sure msqld is running in the process list; it is supposed to start when the computer boots. Then do a Cold Start (see section above).

7.1.4 Electronic Logbook and Beam Accounting

Two tools are available for logging information by the shift workers: (1) The Electronic Logbook “halog”, and (2) The Hall Beam–Time Accounting Table.

The electronic logbook is a web-based repository of logbook data. There are two ways to make entries: One can use the halog GUI (type “halog” and make your entry), or one may use a script to insert a file. Some data from EPICS and scalers, among other things, are inserted automatically into halog on each start-of-run and each end-of-run. These data also get written into files with the run number in their name in /epics/runfiles. Data appear on the web at a certain URL ⁵. It is recommended that one software expert from the experiment be assigned to modify the logging scripts as he or she sees fit.

The Hall Beam–Time Accounting Table is the mechanism to summarize and record how the beam time in a shift was spent. The shift leader is responsible for submitting this table at the end of the shift. When submitted, the data are logged in a database and

⁵<http://www.jlab.org/~adaq/halog/html/logdir.html>

a summary is e-mailed to various people like the run coordinators and the hall leader. When you come on shift, the GUI is probably already running. If not, you may start it by logging onto `adaql1` as the `adaq` account and type `"bta"`. It is a fairly obvious GUI, but there is also some online help.

7.1.5 Port Servers

Portservers are devices on the network that allow access to RS232 ports. Here is how to connect from a computer: `"telnet hatsv5 2011"` will connect to the portserver at IP `hatsv5` and port 11. Note, the offset of 2000 is needed. For dealing with HV, it is best to use a Linux PC for which the keymap is `F1 = PF1` and `F2 = PF2`.

If another person is connected to a certain port, you cannot connect. To bump off another user, login as root with password available from the paper posted on the wall of the counting room (or ask run coordinator) as follows `"telnet hatsv5"` as user = root. At the prompt, type `"kill tty=4"` to clear port 4, then `"exit"`. Now you can `"telnet hatsv5 2004"`.

7.2 Trigger Hardware and Software ^{6 7}

The Hall A trigger was designed by the University of New Hampshire. Here we give a brief overview of the hardware arrangement, the logic of the trigger, and the usage of the software control. Diagrams of the hardware layout are shown in accompanying figures.

Scintillators make the main trigger in each spectrometer arm. For coincidence experiments a coincidence is formed between the spectrometer arms. The main trigger is formed by requiring that scintillator planes S1 and S2 both fired (and both phototubes of the paddles that got a hit) in a simple overlap. To repeat, the trigger requires that one paddle in S1 and one in S2 both got a hit in both of their PMTs (4 PMTs total). The coincidence between spectrometers is formed in an overlap AND circuit. The Right Spectrometer singles triggers are called T1, the Left Spectrometer triggers are called T3, and the coincidence triggers are T5. Other triggers might be formed which require other detectors to measure the efficiency of the main trigger. The most important is T2 on R-arm and T4 on L-arm, whose definition has changed over time but typically require 2 out of 3 from among the S1, S2, and Cerenkov detectors (i.e. the "or" of S1 is used, etc).

The Hall A HRS trigger system is remotely configured by CAMAC modules. The main change that can occur during an experiment is in the delays required to adjust the timings of triggers which change with momentum and particle ID relevant for coincidence setup only. Of course for single arm running one may just use the defaults, but it may still be a wise investment in 2 minutes time to download in order to make sure of the state of the modules. If the power is turned off, the CAMAC modules certainly must be reprogrammed. Instructions to download the trigger are given below.

⁶ *CVS revision* Id: trigger.tex,v 1.4 2003/08/01 20:34:06 rom Exp

⁷ Authors: R.Michaels <mailto:rom@jlab.org>

Table 7.1: Port Servers for DAQ

server IP	Port	Device
hatsv3	1	vt100 Dumb Terminal
hatsv3	2	ROC1 Lower Fastbus Crate
hatsv3	3	TS0 Trig. Super. VME Crate
hatsv3	4	R-arm Upper HV Crate
hatsv3	5	R-arm Lower HV Crate
hatsv3	8	ROC2 Upper Fastbus Crate
hatsv4	1	vt100 Dumb Terminal
hatsv4	2	ROC3 Lower Fastbus Crate
hatsv4	3	ROC4 Upper Fastbus Crate
hatsv4	5	HV Crate
hatsv4	6	RICH HV Crate
hatsv4	7	RICH VME Crate
hatsv4	14	TS1 Trig. Super. VME Crate
hatsv5	1	vt100 Dumb Terminal
hatsv5	2	e-P Crate 1
hatsv5	3	Moller 1
hatsv5	4	Moller 2
hatsv5	8	Compton ROC3
hatsv5	9	Compton ROC4
hatsv5	10	Compton ROC5
hatsv5	11	Beamline HV
hatsv5	12	e-P Crate 2
hatsv5	13	ARC Energy
hatsv5	14	ROC14 VME Crate
hatsv5	15	ROC15 VME Crate
hatsv12	5	Compton ROC1
hatsv12	6	Compton ROC2
hatsv15	-	2nd Floor Counting Room
hatsv9	4	Parity DAQ Crate

The trigger design is quite flexible and it is relatively easy to add detectors to define new trigger types or to modify existing ones, so long as the detector is fast enough. The trigger supervisor also allows for the possibility of 2nd level triggers which could be used for a later decision.

Here we describe the software control of the CAMAC modules involved in the trigger. The software control was written by Tim Smith and Jeff Vieregg of MIT with some input from Bob Michaels. There are four types of modules that are controlled: (1) Discriminators; (2) Delay Units; (3) Memory Lookup Unit (4) AND/OR Modules

Here are the instructions to download the trigger. First login to the ADAQ Linux box `adaql1` or `adaql2` (and no others) as “`atrig`” account. (E.g. `ssh adaql1 -l atrig`). The Run Coordinator should know the password. Type “`trigsetup`”. A self-explanatory graphical user interface pops up, where if you are in a coincidence experiment setup you must enter the momenta and particle ID’s and then press “Download” and WAIT for it to finish and do not press Ctrl-C. However, for single arm running like Spin Duality or GDH, just press “Download” with the defaults, and WAIT for it to finish and do not press Ctrl-C. The user should look for suspicious error messages in the window from which `trigsetup` was launched, e.g. to check if connection to the crate is ok.

If individual modules need to be modified for test purposes etc. (e.g. to change thresholds), one may use the expert mode. Login to an ADAQ linux box as explained above, then type “`trigsetup mapfile`” where `mapfile` is the name of the trigger map file. Some examples of map files are in `/home/atrig/trigger`, see `trigger_left.map` and `trigger_right.map` for the left and right spectrometers respectively. These are default databases. One can modify each module on the fly, save the database, etc.

After you download, a record of what was sent is put into a file (`/home/atrig/trigger/trigger.setup`) which gets put automatically into the electronics logbook “`halog`”. Also, whenever a CODA run is started, this file is inserted as a special event type 136 at the start of run. This will be the setup IF the download was successful. It is also interesting to know what is actually in CAMAC, but that can only be done in expert mode, and the delays cannot be read from CAMAC. The simplest way to be sure about what is in the trigger is to download again.

7.3 Online Analysis, Data Checks ^{8 9}

The following tools are available for checking data online.

Scaler Display and Scaler Events

Scaler rates and values are displayed using a MOTIF based display called “`xscaler`” written by C. Howell of Duke University. Normally this is already running on `adaqs2` or `s3`. If it is not running, login as `adaq` and go to the appropriate directory, which is `/home/adaq/$EXPERIMENT/electron/scaler` and `/home/adaq/$EXPERIMENT/hadron/scaler`

⁸ *CVS revision* Id: `online-analysis.tex,v 1.2 2003/08/01 20:34:06 rom Exp`

⁹ Authors: R.Michaels <mailto:rom@jlab.org>

R. Michaels (Aug 2003)

Coincidence Trigger Electronics on Left Arm

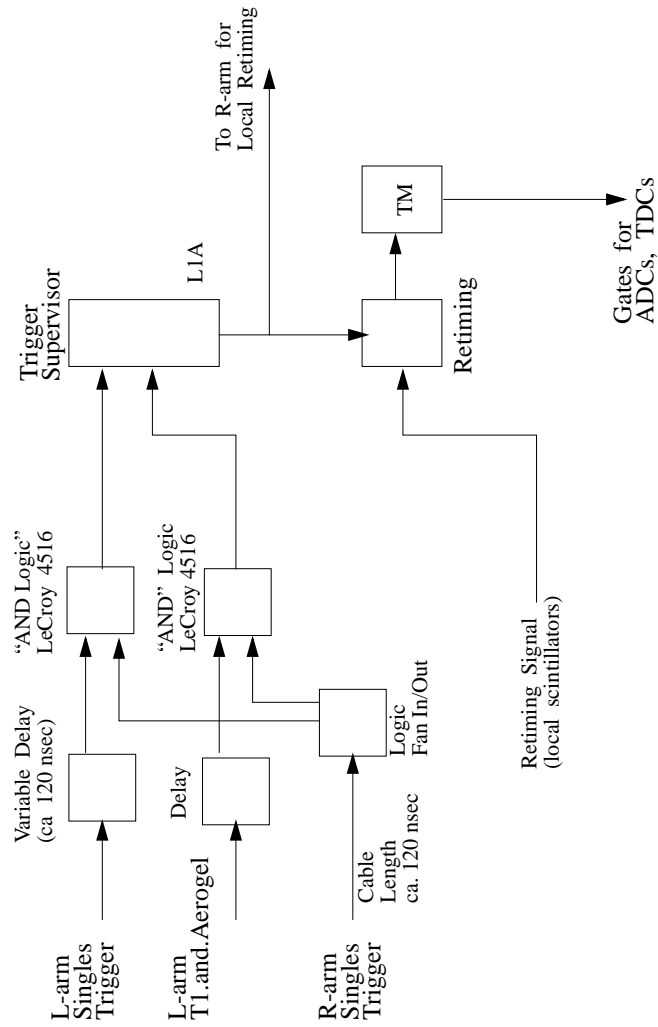


Figure 7.2: Coincidence Trigger Circuit.

for the E-arm and H-arm respectively where \$EXPERIMENT is an environment variable like e95001. Then type “xscaler” there. *Remember* to push the button “Start”. The first several pages are the scaler rates and the next half of the pages are the absolute scaler counts. The scalers are cleared at the beginning of each CODA run. Scalers are read out at approximately 0.5 Hz and injected into the CODA data-stream as event type 140. A file “scaler_history.dat” is maintained which is a complete history of scaler readings at the end of each run that ended normally. For 1-TS mode, this file is in /home/adev/scaler.

7.3.1 Analysis using ESPACE or C++ Analyzer

ESPACE is the main offline software package for analyzing Hall A experiments. It is being replaced by a ROOT/C++ analyzer. Both may be used for rapid near-online analysis in the counting room. These codes are documented in separate chapters, but it is worth mentioning here in a list of essential tools for checking data.

7.3.2 Dataspy and Dhist

Dataspy and Dhist are somewhat obsolete online diagnostic programs. It remains to be seen if we replace these by an offshoot of the C++ analyzer. The purposes of dataspy and dhist are: (1) To print out randomly sampled detector data; and (2) To automatically plot to the screen histograms of online data. Dhist is actually a shell script which runs the executable “dplot”. For some online help, simply type “dataspy” or “dplot”. These codes analyze a random sample of of *raw*, *uncut* data in real time from the CODA computer. The data are distributed on the network by a server which obtains data from shared memory.

This paragraph assumes you are on shift and wish to run dhist. While “dplot” can run in several ways, let’s be definite: Log in to adaqh2 (or s3) as “adaq” account. If dhist isn’t running, type “dhist”. Now you will see a reminder of what directory to go to and that you should type “./dhist” there.

There are optional interfaces “dopte” and “dopth” for turning on/off the histogram pages. The dopte(h) interfaces also show an alarm status for the histograms by statistical comparison to a set of reference histograms. To start these interfaces, type “dopte” or “dopth” for the E-arm and H-arm respectively.

dhist makes about 20 pages of plots which pop up on the workstation screen and remain for a few seconds in succession. Each page also results in a postscript file for printing, and there is a histogram file dplot.his which one can view in PAW.

Appendix A

Hall Checklist

A.1 Pre Beam and Cryo Target Checklist

Cryo Target Pre Beam Checklist Date----- time -----

Last revised 3/6/98

This checklist will be completed after every restricted access to Hall A during which maintenance is performed

People checking list -----

Electron Arm

Spectrometers

- correct angle ----- (not to be used for calculations)
- correct pointing -----(not to be used for calculations)
- collimator operation at 3 positions
- check spectrometer for obstructions to movement
- check intergen bottles for correct pressure
- insure that 15 degree stop pin is installed

Vacuum

- blower on at controls under spectrometer
- turbo on at turbo controller in rack # 1H71B01
- pump valves open at valve controller in rack # 1H71B01 channel #2
- convectron gages read "0" millitorr
- roughing valve closed at rack #1H71B01 channel # 4
- cold cathode gages on at gage in rack # 1H71B01 cold cathode j 5x10-5
- actual cold cathode reading -----
- entrance & exit vacuum windows functional

magnet controls

Q1

- Q1 full of liquid (80%) actual-----

--- open lead flows on Q1 to 80 slm as read from rack #Q171Q
 --- actual lead flows A_____ B_____
 --- cctv camera on and focused

D1

--- Dipole full of liquid (80%) actual_____
 --- open lead flows on Dipole to 80 slm as read from rack #D171Q
 --- actual lead flows A_____ B_____

Q2

--- Q2 full of liquid (80%) actual_____
 --- open lead flows on Q2 to 60 slm as read from the Q2 instrument rack meter.
 --- actual lead flows A_____ B_____

Q3

--- Q3 full of liquid (80%) actual_____
 --- open lead flows on Q3 to 60 slm as read from the Q3 instrument rack meter.
 --- actual lead flows A_____ B_____

Power supplies

POWER SUPPLY TURN ON PROCEDURES

--- Verify UPSs as operational on all power supply controls (with no current on magnets only)
 --- red rotating beacons on

Q1:

--- visual inspection of main current leads, dump resistor, and lead flags (for condition, visual shorts, etc.)
 --- unlock power disconnect switch and turn on AC power
 --- visually check power supply for faults
 --- when all faults have been cleared, insure that power supply is in remote control

Q2:

--- visual inspection of main current leads, dump resistor, and lead flags (for condition, visual shorts, etc.)
 --- unlock power disconnect switch and turn on AC power
 --- turn on both sets of three pole breakers located on power supply
 --- visually check power supply for faults
 --- when all faults have been cleared, lift lever on lower right side of supply
 --- insure that power supply is in remote control

Q3:

- visual inspection of main current leads, dump resistor, and lead flags (for condition, visual shorts, etc.)
- unlock power disconnect switch and turn on AC power
- turn on both sets of three pole breakers located on power supply
- visually check power supply for faults
- when all faults have been cleared, lift lever on lower right side of supply
- insure that power supply is in remote control

Dipole:

- visual inspection of main current leads, dump resistor, and lead flags (for condition, visual shorts, etc.)
- unlock power disconnect switch and turn on AC power
- turn on power lever on right upper side of supply
- visually check power supply for faults on supply and at rack #
- when all faults have been cleared, insure that power supply is in remote control
- cctv camera on and focused
- check power supply for proper polarity
- NMR gradient compensation for on and proper polarity

Hadron Arm

Spectrometers

- correct angle ----- (not to be used for calculations)
- correct pointing -----(not to be used for calculations)
- collimator operation at 3 positions
- check spectrometer for obstructions to movement
- check intergen bottles for correct pressure
- insure that 15 degree stop pin is installed

Vacuum

- blower on at controls under spectrometer
- turbo on at turbo controller in rack # 1H71B01
- pump valves open at valve controller in rack # 1H71B01 channel #2
- convectron gages read "0" millitorr
- roughing valve closed at rack #1H71B01 channel # 4
- cold cathode gages on at gage in rack # 1H71B01 cold cathode j 5x10-5
- actual cold cathode reading -----
- check dipole turbo for on

magnet controls

Q1

- Q1 full of liquid (80%) actual-----
- open lead flows on Q1 to 80 slm as read from rack #Q171Q

--- actual lead flows A----- B-----
 --- cctv camera on and focused

D1

--- Dipole full of liquid (80%) actual-----
 --- open lead flows on Dipole to 80 slm as read from rack #D171Q
 --- actual lead flows A----- B-----

Q2

--- Q2 full of liquid (80%) actual-----
 --- open lead flows on Q2 to 60 slm as read from the Q2 instrument rack meter.
 --- actual lead flows A----- B-----

Q3

--- Q3 full of liquid (80%) actual-----
 --- open lead flows on Q3 to 60 slm as read from the Q3 instrument rack meter.
 --- actual lead flows A----- B-----

Power supplies

POWER SUPPLY TURN ON PROCEDURES

--- Verify UPSs as operational on all power supply controls (with no current on magnets only)

--- red rotating beacons on

Q1:

--- visual inspection of main current leads, dump resistor, and lead flags (for condition, visual shorts, etc.)

--- unlock power disconnect switch and turn on AC power

--- visually check power supply for faults

--- when all faults have been cleared, insure that power supply is in remote control

Q2:

--- visual inspection of main current leads, dump resistor, and lead flags (for condition, visual shorts, etc.)

--- unlock power disconnect switch and turn on AC power

--- turn on both sets of three pole breakers located on power supply

--- visually check power supply for faults

--- when all faults have been cleared, lift lever on lower right side of supply

--- insure that power supply is in remote control

Q3:

--- visual inspection of main current leads, dump resistor, and lead flags (for condition, visual shorts, etc.)

--- unlock power disconnect switch and turn on AC power

--- turn on both sets of three pole breakers located on power supply

--- visually check power supply for faults

--- when all faults have been cleared, lift lever on lower right side of supply

--- insure that power supply is in remote control

Dipole:

--- visual inspection of main current leads, dump resistor, and lead flags (for condition, visual shorts, etc.)

--- unlock power disconnect switch and turn on AC power

--- turn on power lever on right upper side of supply

--- visually check power supply for faults on supply and at rack #

--- when all faults have been cleared, insure that power supply is in remote control

--- cctv camera on and focused

--- check power supply for proper polarity

--- NMR gradient compensation for on and proper polarity

Target

--- windows functional

--- cctv cameras "on" and focused

--- target light "on"

--- backing pump "on" at pump

--- turbo "on" at rack # 1H75B09

--- turbo valve "open" at rack # 1H75B09 channel # 1

--- gages operational

--- convectron "0" millitorr at rack # 1H75B09

--- cold cathode 5×10^{-4} at rack # 1H75B08

--- actual cold cathode reading -----

Exit beam tube

--- backing pump "on" at pump and operational

--- valve "open" controlled at rack # 1H75B09 channel # (temp manual at pump)

--- turbo "on" at rack # 1H75B09

--- gages operational

--- convectron "j5" millitorr at rack # 1H75B09
 --- actual convection reading -----
 --- diffuser cooler on
 --- diffuser water level ok

Entrance beam tube

--- insure that Møller turbo is on and running
 --- insure that Møller target cooler is on and operational
 --- insure that there is cooling water flow to the Møller Dipole
 --- insure that ep turbo is on and running
 --- beam line vacuum valves "open" (visually checked)
 --- instrument air compressor functioning normally

Hall

--- all interlocks in rack # 1H75B08 indicate green
 --- check 3 Møller power supplies for on (lights flashing at magnets)
 --- check location and operational readiness of Ion chambers
 --- correct LCW flow and pressure (100 psi supply and 60 psi return)
 --- cctv cameras on and focused
 --- cctv monitors at X terminal off
 --- clear of unnecessary equipment
 --- Man lift and Forklift in truck ramp
 --- perform pre sweep of run safe boxes
 --- unnecessary personnel exit Hall
 --- move Electron spectrometer stairs clear of lower balcony
 --- ensure polar crane is positioned over the entrance beam pipe
 and that power is off at the power disconnect switch
 --- ensure spectrometer entrance window guards are removed
 --- ensure target window guards are removed

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A.2 Post Beam Checklist for Maintenance Period

Revised 2/22/99

This checklist will be completed prior to every restricted access to Hall A during which maintenance is performed

People checking list -----

Spectrometers

- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY
- Install yellow covers on inlets to spectrometers

Target

- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY
- Install protective shields over vacuum windows if Cryo target is installed

Power supplies

(from a computer console)

Electron

- set current to 0 amps by remote control on Q1
- set current to 0 amps by remote control on Q2
- set current to 0 amps by remote control on Q3
- set current to 0 amps by remote control on Dipole

Hadron

- set current to 0 amps by remote control on Q1
- set current to 0 amps by remote control on Q2
- set current to 0 amps by remote control on Q3
- set current to 0 amps by remote control on Dipole

Entrance beam tube

- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY

Exit beam tube

- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY

Dump

- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY
- Inspect visible areas for water leaks

Hall

- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY
- Inspect power supply platforms, spectrometers, and the rest of the Hall, looking for water leaks and cryogenic plumes
- Man lift and Forklift removed from truck ramp

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A.3 Post Beam Checklist for an Extended Time

Last revised 2/22/99

This checklist will be completed prior to extended restricted accesses to Hall A.

People checking list _____

Power supplies

(from the control room)

Electron

Q1

- set current to 0 amps by remote control
- turn output off by remote control

Q2

- set current to 0 amps by remote control
- turn output off by remote control

Q3

- set current to 0 amps by remote control
- turn output off by remote control

Dipole

- set current to 0 amps by remote control
- turn output off by remote control

Hadron

Q1

- set current to 0 amps by remote control
- turn output off by remote control

Q2

- set current to 0 amps by remote control
- turn output off by remote control

Q3

- set current to 0 amps by remote control
- turn output off by remote control

Dipole

- set current to 0 amps by remote control
- (from the Hall)

Target

- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY
- Install protective shields over vacuum windows if Cryo target is installed
- target light off at target
- cctv cameras off at target

```

--- turbo off at rack #
--- turbo valve closed at rack #                switch #
--- backing pump off and bled up  at pump
--- gages operational
--- windows functional

```

Spectrometers

--- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY

```

--- turbo valves closed at valve controller in rack # 1H71/72B08 switch #
--- turbo off at turbo controller in rack # 1H71/72B08
--- blower off at controls under spectrometer
--- pump valves closed at valve controller in rack # 1H71/72B08 switch #
--- convectron gages on
--- cold cathode gages off at gage in rack #
--- windows functional

```

Electron

Q1

```

--- ensure 0 current status on local power meter
--- ensure that the set to and ADC readouts all equal "0"
--- turn off Q1 LCW supply valve slowly and lock it in the off position

```

Q2

```

--- ensure 0 current status on local power meter
--- ensure that the set to volts readout equals "0"
--- ensure that the set to current readout equals "0"
--- switch off input power at power supply
--- switch off power at safety disconnect and lock switch in the off position

```

Q3

```

--- ensure 0 current status on local power meter
--- ensure that the set to volts readout equals "0"
--- ensure that the set to current readout equals "0"
--- switch off input power at power supply
--- switch off power at safety disconnect and lock switch in the off position

```

Dipole

```

--- ensure 0 current status on local power meter
--- switch off input power at power supply
--- switch off power at safety disconnect and lock switch in the off position

```

Hadron

Q1

- ensure 0 current status on local power meter
- ensure that the set to and ADC readouts all equal "0"
- turn off Q1 LCW supply valve slowly and lock it in the off position

Q2

- ensure 0 current status on local power meter
- ensure that the set to volts readout equals "0"
- ensure that the set to current readout equals "0"
- switch off input power at power supply
- switch off power at safety disconnect and lock switch in the off position

Q3

- ensure 0 current status on local power meter
- ensure that the set to volts readout equals "0"
- ensure that the set to current readout equals "0"
- switch off input power at power supply
- switch off power at safety disconnect and lock switch in the off position

Dipole

- ensure 0 current status on local power meter
- switch off input power at power supply
- switch off power at safety disconnect and lock switch in the off position

Entrance beam tube

- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY
- beam line vacuum valves closed
- E P turbo valve closed
- E P turbo off
- E P backing pump off and vented to atm.
- Møller turbo valve closed
- Møller turbo off
- Møller backing pump off and vented to atm.
- instrument air compressor functioning normally

Exit beam tube

- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY
- beam tube valve closed
- exit beam tube turbo valve closed

- exit beam tube turbo off
- exit beam tube backing pump off and vented to atm.
- cold cathode gage off
- convectron gages on
- Dump
- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY

- turn off diffuser cooler
- Inspect visible areas for water leaks

Hall

- NOTE : LOOK FOR "RADIATION AREA" SIGN and OBEY

- Inspect power supply platforms, spectrometers, and the rest of the Hall, looking for water leaks and cryogenic plumes
- cctv cameras off
- clear of unnecessary equipment
- Man lift and Forklift removed from truck ramp
- Doors unlocked

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CVS \$Id: all.tex,v 1.2 2003/06/05 23:29:59 gen Exp \$

Bibliography

- [1] W. Barry. Pr-90-009. Technical report, CEBAF, 1990. 27
- [2] C. Hyde-Wright et al. Beam position studies for e93050. private communication. 27
- [3] T. Powers. private communication. 28
- [4] CODA WWW page. <http://coda.jlab.org/>. 75, 233
- [5] PAW WWW page. <http://wwwasd.web.cern.ch/wwwasd/paw/>. 79
- [6] R.D. Mc Carty. Hydrogen technology survey: Thermophysical properties. Technical Report N76-11297, NBS, 1975. 86
- [7] W. Schmitt and C. Williamson. Boiloff rates of cryogenic targets subjected to catastrophic vacuum failure. Technical Report 90-02, Bates Internal Report, Sept 1990. 92
- [8] F. Duncan K. McCormick and J. Goity. A user's guide to the hall a cryotarget control system. Technical report, Jefferson Lab Hall A, Sept 1997. 94, 97
- [9] F. Garibaldi et al. A waterfall target for electron scattering experiment. *Nucl. Instrum. Meth.*, A314:1, 1992. *SPIRES entry, DOI server*. 98
- [10] G. Bartozek et al. The e760 lead-glass calorimeter: Design and initial test results. *Nucl. Instrum. Meth.*, A310:47–60, 1990. 172
- [11] J.A. Appel et al. Performance of a lead-glass electromagnetic shower detector at fermilab. *Nucl. Instrum. Meth.*, 127:495–505, 1975. 172
- [12] M. Goldberg et al. Radiation induced coloring of cerenkov coutner glasses. *Nucl. Instrum. Meth.*, 108:119–123, 1975. 172
- [13] T. Ferbel, editor. *Experimental Techniques in High-Energy Nuclear and Particle Physics*. Addison-Wesley Publishing Co., Inc., 1991. 172
- [14] Cebaf conceptual design report (cdr), 1990. 172

- [15] C. Lippert et al. Particle discrimination in medium-energy physics with an aerogel cerenkov detector. *Nucl. Instrum. Meth.*, A333:413–421, 1993. 181
- [16] L. C. Alexa et al. Empirical tests and model of a silica aerogel cerenkov detector for cebaf. *Nucl. Instrum. Meth.*, A365:299–307, 1995. 183
- [17] G. J. Lolos et al. Performance and design characteristics for the hall a aerogel cerenkov counters. *Nucl. Instrum. Meth.*, A385:403–411, 1997. 183
- [18] E. J. Brash et al. Operational performance of the hall a mirror aerogel cerenkov counter. *Nucl. Instrum. Meth.*, A487:346–352, 2002. 185
- [19] EPICS documentation can be found at: <http://www.aps.anl.gov/asd/controls/epics/EpicsDocumentation/WWWPages/EpicsDoc.html>. 227